

A COURSE IN SOILLESS GARDENING

A Project

Presented to

**the Faculty of the School of Education
The University of Southern California**

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Education

by

Joel E. Winans

June 1950

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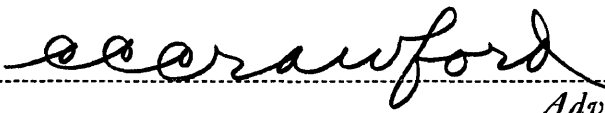


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This project report, written under the direction of the candidate's adviser and approved by him, has been presented to and accepted by the Faculty of the School of Education in partial fulfillment of the requirements for the degree of Master of Science in Education.

Date.....April 15, 1950.....


Adviser


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March 27, 1950

To whom it may concern:

This is to certify that permission has
been given to Mr. Joel E. Winans to present
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A handwritten signature in cursive script, reading "C. C. Crawford". The signature is written in dark ink and is positioned above the printed name.

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Professor of Education

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PREFACE TO TEACHERS
PURPOSES OF THIS COURSE OUTLINE

This project is an experimental syllabus for a course in soilless gardening, otherwise termed hydroponics, solution culture, chemiculture, nutriculture, and so on. The essential feature of the various systems is the supplying of the roots of plants with chemical solutions containing the 11 or 12 elements known to be essential for plant growth.

Soilless culture of plants has long been practiced as a scientific technique for studying plant nutrition under controlled conditions, and was developed in the late 1920's into an economically feasible means of flower and vegetable production. Thus it can be practiced as an interesting hobby and also as a reasonably successful practical occupation. At present, it should not be considered as a substitute for agriculture, but rather as a suitable alternative where conditions of limited space or poor soil make it advisable. Its greatest commercial application has been in greenhouse production of flowers and off-season vegetables. During the last war the Army Air Forces Quartermaster Corps produced large quantities of vegetables by chemical gardening in isolated barren islands of the Atlantic and Pacific, and in Japan, where soil-grown vegetables were not suited for use because of danger of disease contamination.

Some of the main obstacles to the use of soilless gardening in home production are described in Chapter 10. On the favorable side is the fact that the cost of chemicals is potentially a minor item, and that the labor involved is less than in soil gardening. With the overcoming of problems of (a) obtaining reasonably priced chemicals

in retail quantities, (b) obtaining cheaper home-type equipment, and (c) developing efficient techniques of home production, the use of soilless gardening as a practical productive home activity could be expected to increase considerably.

As a classroom course, soilless gardening could perhaps best be integrated into a general science course; it could also perhaps fit into courses in chemistry, biology, botany, and agriculture. It would seem to be a promising course in the adult education field.

The procedure followed in preparing this course outline was to survey the available books on soilless gardening, together with most magazine articles since 1940, and to select, adapt, organize, and present the most suitable materials in a series of ten chapters, preceded by a Preface to Students. Each chapter consists of five sections, beginning with an introductory motivating and orienting section, then proceeding to the main body of the presentation or exposition. This is followed by suggested assignments, split into more immediate, exploratory projects, and more remote, practical, vocational, or "target" projects. Sample evaluation procedures are given, and finally, source materials for each chapter.

This course outline does not assume familiarity with chemistry, physics, biology, or high school mathematics, but introduces some procedures related to these subjects at various appropriate points throughout the course. The wise teacher will adapt the materials to the interest and maturity of the students.

It would seem advisable that a teacher undertaking to teach this course should have experimented with soilless gardening in his own back

yard with some degree of success, and be familiar with the common causes of failure and with short cuts and efficient methods. Some attention and planning will have to be given to the problem of the care of the soilless gardening projects between class meetings. Such duties might be rotated among the class members, or performed by a laboratory assistant or by the instructor.

Whether the time has come when many people can carry on soilless gardening in their back yards may be an open question. It seems probable, however, that there are no permanent obstacles in this direction, and it may be a matter of only a few years until this becomes possible. Spessard's recent little book, "The Tanks are Coming", cited in the Reserve Shelf Books, would seem to contribute much to this aim.

PREFACE TO STUDENTS
GETTING ACQUAINTED WITH SOILLESS GARDENING

To many people, soilless gardening is a new and strange, almost magical, method of growing plants. In reality, there is very little that is new about it, and it is a perfectly natural, although artificially controlled process. For many years scientists have studied the results of changing the amounts of chemical food elements supplied to plants. In order to do this accurately, they have had to avoid using soil, for very good scientific reasons, since soil introduces several unknown and uncontrolled chemical factors into their experiments. Feeding plants the needed food elements in carefully compounded solutions was the only way out, and has been practiced since around 1850 in chemical laboratories.

It was not until about 1925 that scientists had learned enough of the secrets of plant growth that they were able to use these soilless methods in practical crop raising. Success came first with flowers, and followed in 1929 onward with vegetables and field crops. Some of the results achieved with soilless methods were much better than average soil crop yields. Amateurs began to try out soilless gardening methods in their back yards, sometimes with surprisingly good results. In some cases, although the money value of products raised was nothing remarkable, still hobbyists had the fun of growing plants in a new and novel way. The popularity of soilless gardening in the late 'thirties and early 'forties may be judged by a considerable number of magazine articles and several books written on this subject about that time.

During the war years, chemical gardening was demonstrated to be a practical method of supplying G. I.'s in isolated barren locations with fresh salad vegetables. In Japan also, large gravel culture installations have furnished all the needed fresh vegetables to occupying personnel, thereby conserving soil resources as well as avoiding possible disease contamination from soil-grown vegetables. Japanese scientists have taken great interest, and have assisted with this soilless gardening project, seeing in this method a possible means of increasing Japan's limited soil-grown food supplies.

In organizing these various soilless gardening production units, the Army called on experienced greenhouse operators who have been using soilless methods of production since around 1940 to produce out-of-season crops for better than average prices. Curiously, the serious use of soilless gardening by the army was preceded by its use as a hobby by convalescing air-force veterans in Florida. The remarkable results they obtained suggested the possibility of its serious use in food production in barren islands of the Atlantic and the Pacific. In spite of having to distill ocean water and transport the chemicals long distances, the costs of producing these vegetables were not prohibitive, as might be expected.

Here are some suggestions for you to follow in order to get a "How-do-you-do" acquaintance with this new method of growing plants:

(a) Obtain and have shown one or two of the moving pictures listed in the "List of 16 mm. Motion Picture Films". (b) Look through the illustrations in several of the Reserve Shelf Books, or have them shown to the class with an opaque projector, following the selected list in

"Sources Useful for Orientation", heading "Pictures in Reserve Shelf Books". (c) Read sections in the Reserve Shelf Books which are introductory or general in nature; see "Sources Useful for Orientation", heading "Readings in Reserve Shelf Books". (d) Read the magazine articles suggested in "Sources Useful for Orientation", heading "Magazine Articles". (e) Arrange a visit to a nursery which practices soilless methods, or to a plant physiology laboratory. (f) Obtain some samples of vegetables or strawberries grown by soilless gardening methods and give them a taste test.

It is with the hope that you will find in soilless gardening a new and fascinating hobby that this book has been written. In addition, what you learn by its study may become of practical value to you, either as a full-time occupation, or as a means of growing part of your own produce and flowers. Even if you adopt soil methods exclusively, this course should give you a better working knowledge of the needs of plants that will help you get better results.

PART I. STARTING SOMETHING
HOW TO SET UP A SIMPLIFIED PROJECT

Since you have given the work of others in soilless gardening a quick once-over, we think you may be anxious to undertake some project or experiment of your own which, although on a small scale, will be real soilless gardening. When that is on its way, there will be time enough to dig into the finer details, short-cuts and trouble-shooting. The following two chapters are intended to help you with such a project.

CHAPTER 1. SIMPLIFIED PROCEDURES HOW TO START WITH READILY AVAILABLE SUPPLIES

Soilless gardening is thought by many people to be a difficult and highly specialized business. While there is much that can be learned about the fine points of chemiculture, you, even though an amateur, can make a good start with nothing more complicated than a flower pot, a tin can, a ten cent package of chemicals, some sand, and a tomato plant from the nurseryman. Or, with a little more care in planning, you can set up a continuous drip solution supply that will take less attention and really produce good results. Follow the descriptions in this chapter for a good send-off in this fascinating hobby.

A. SOME PRACTICAL AMATEUR ARRANGEMENTS How to provide necessary factors for plant growth

Following are some practical suggestions to aid you in launching into soilless gardening as a hobby in your home. You may be interested in novel and decorative displays for indoors, or you may want to take the first steps toward raising flowers for bouquets or vegetables for the table.

1. How to make attractive house displays. A bulb or flowering plant growing in solution is an object of interest as well as one of beauty. Glazed flower pots, painted glass bowls, or jars of attractive design can be used in your display. Many plants are prized as house decorations for their foliage or flowers. Some foliage plants are English ivy, rubber plants, Kentia palms, and so forth. Suitable flowering plants include Mira lemon, calla lillies, amaryllis, gera-

niums, fuchsias, and lilies-of-the-valley. For a more complete list, see the pages cited in Laurie, at the end of this chapter.

Many attractive as well as functional arrangements have been worked out to supply plants with a constant supply of solution. In the drip arrangement, you invert a quart jar of solution on a dish, and use a capillary tube siphon to drip the solution onto the sand or into the jar containing the plant's roots. In another arrangement, a wick draws the nutrient solution up into the sand in which the plant's roots are growing. For pictures and further description, see Ellis, cited at the end of the chapter.

For those who wish to pay the price, some very artistic double vases are available commercially, which supply nutrients by a wick principle to the plants growing in sand.

You may wish to work out your own arrangement, according to your own preferences. The essential features, from the standpoint of the plant's needs, are: (a) Something to hold the plant upright. This may be sand or gravel around the plant's roots, or, if they hang in solution, the stem may be held firmly in a cork, or in a wire basket with excelsior. (b) A supply of nutrients to the roots, whether supplied by a drip system, occasional pouring or flooding, immersion of roots in a container of solution, or the use of a wick. (c) A supply of air to the roots, whether dissolved in the water by bubbling, frothing, beating, etc., or by the air spaces in coarse sand or gravel, or by some other method. (d) A provision to catch and re-use the solution that passes through, if you desire. You will do well to read these four

essentials over again carefully, since they state in a nutshell what you must do to carry on soilless gardening by any method. •

You will find that a display of the kind we are describing will stimulate curiosity, give visitors a topic of conversation, and also will be a novel decorative arrangement. A living plant, with gleaming white roots growing in cool water, may be just the thing to give your living room a touch of novel attractiveness.

2. How to grow plants in earthen pots, cans, jars, or something else that's handy. If your set-up doesn't need to be a respectable "Sunday clothes" arrangement for the living room, you can put your plants in quite a variety of receptacles. Coffee or other larger tin cans will do. Punch a hole in the bottom for drainage, fill the can full of coarse sand, set it on top of a slightly smaller can, then dissolve your chemicals according to the instructions on the package you have bought, and plant some seeds in the sand. Pour the contents of the bottom can back into the top once or twice a day, replenishing water used by the plant. Does that seem difficult? For sprouting seeds, use plain water for some seeds, or half-strength solution for some others. See Figure 1, on the following page.

This is the simplest and easiest arrangement to set up, so you should not expect perfectly trouble-free operation. With a little extra planning, you might set up something that will take less attention to keep going. Your cans may get too warm in the sunshine for the best health of the plant roots. If your sand is too fine, the drainage and air supply to the roots may not be just right. Even so,

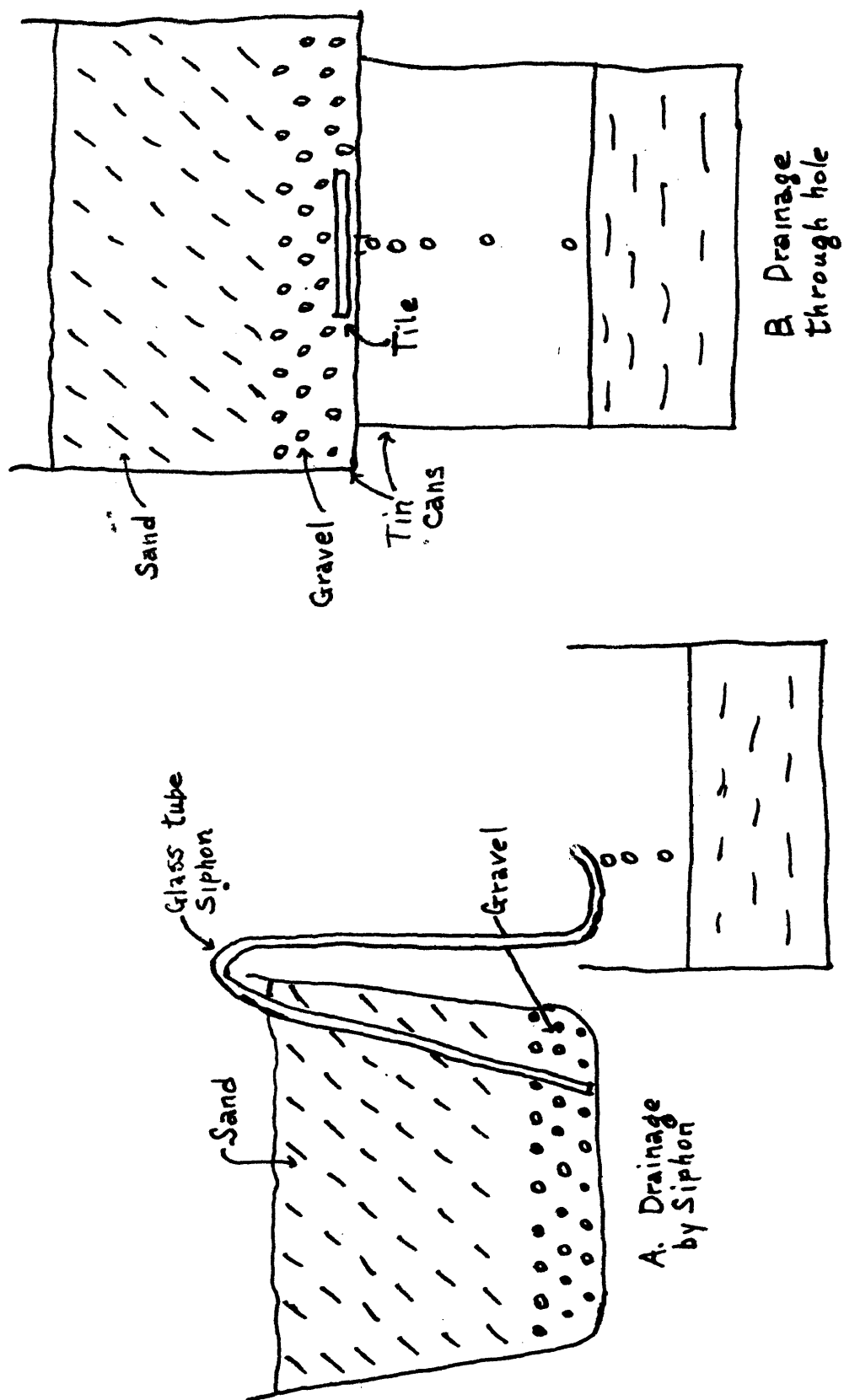


FIGURE 1
 ARRANGEMENT OF SAND
 IN JAR ORGAN

you can get something started, and something that will really work. And it should take you less than a half-hour. So let's worry about the troubles when they come, and not before.

You can substitute a flower-pot for the upper can we mentioned above. Now, suppose you want to use a crock, or glass jar, with no hole for drainage. You can provide drainage with a glass tube siphon, bent in a bunsen burner or ordinary gas flame, or you may try rubber tubing. See Figure 1, A.

3. How to make a continuous drip arrangement. In presenting house displays, we described one way to make a continuous drip set-up. Figure 2 shows another use of the same principle. Use a half-gallon or gallon clothes-bleach or cider jug, supporting it securely in an inverted position. You may substitute a string or cloth for the capillary-tube siphon, using a thick string for faster, or a thin string for slower dripping.

To save labor and attention, you may want to invest in a constant level chicken-watering device. See your feed dealer. The constant-drip arrangement combines easily with an aerating funnel as shown in Figure 2, to provide a continuous air supply into the solution. Each drop of solution falling into the funnel carries down an air bubble with it.

4. How to arrange tomato plants in a series of jars. If you have made a continuous drip device with a gallon or more capacity, you can profitably set up a series of three or four gallon jars with a tomato plant growing in each one. Support the plants as shown in each one. Support the plants as shown in Figure 2, in a can stuffed

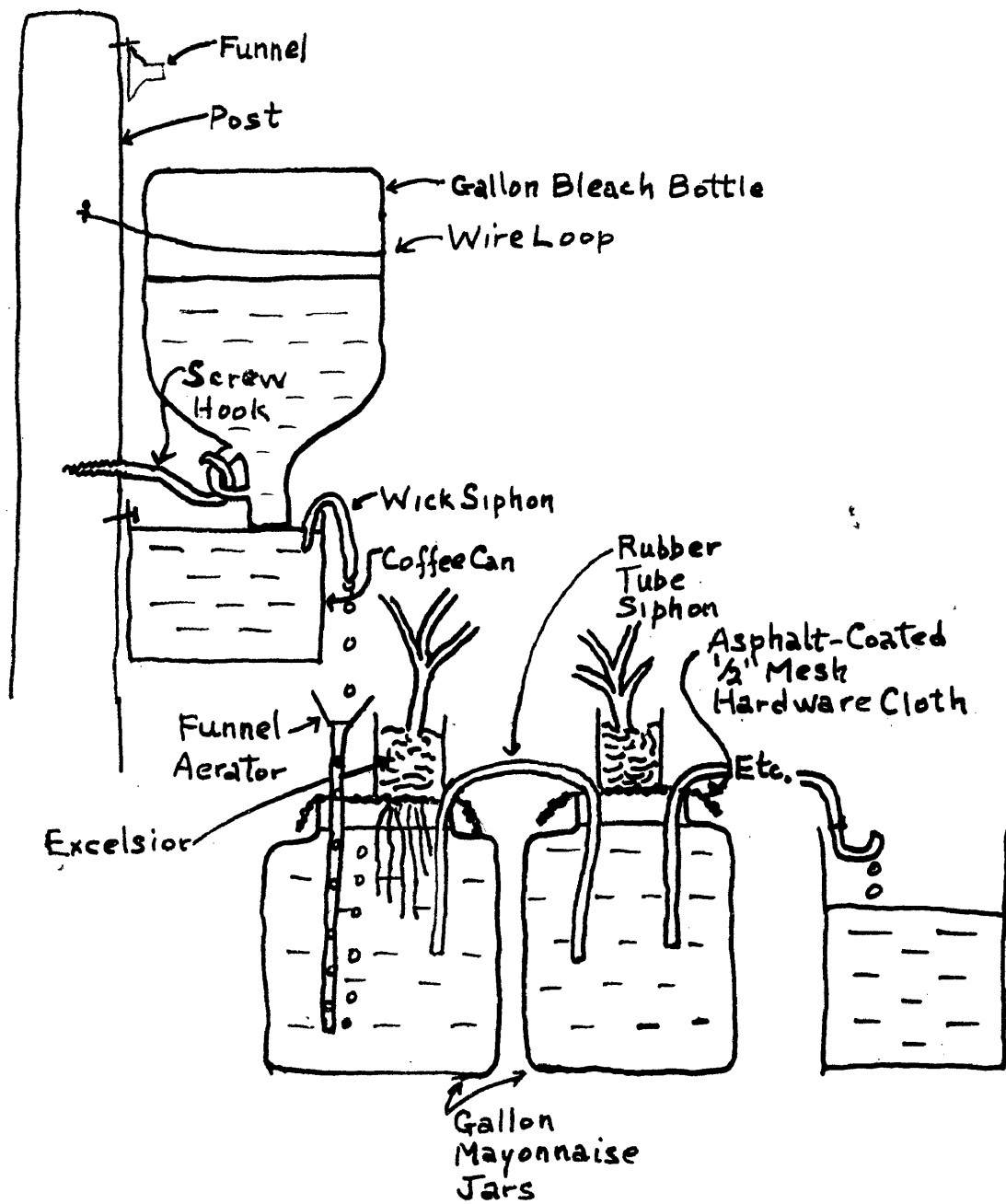


FIGURE 2
ARRANGEMENT OF SERIES OF JARS

with excelsior, cotton wadding (water resistant) or similar material. Place the plant in the can on a screen of $\frac{1}{8}$ in. mesh hardware cloth (coated with paraffin or asphalt paint), bent down over the jar to stay in place.. Fasten the can with small wires to the screen.

Obtain started tomato plants from a nursery, and place in the cans on a thin piece of tissue paper, leaving the soil attached. Have the gallon jars full, and wet the plant roots. In a few days the roots will penetrate the paper and be established in the solution. Connect the jars in a series with rubber tube siphons, and exclude light by wrapping the tops with paper. (Jars should first be painted with aluminum paint.) In the last jar insert the overflow siphon, which regulates the level of the solution in the jars by the level of its tip or outlet.

B. PLANTS AND SOLUTIONS

How to select plants and provide nutrient solutions

In later chapters we will tell you more about preparing solutions and adapting your methods to suit various plants. A few hints will be sufficient to help you get a start at this time.

1. How to choose plants that will do well with least care in soilless gardening. We suggest that you experiment with tomato plants since they have shown themselves to do well in the hands of amateurs. Also you will have something to show for your efforts if and when your plants bear fruit. If you like flowers, try yellow or red cannas. (See Gericke, p. 214.)

2. How to provide solutions. You may buy small packages of chemicals

icals for hydroponics at various seed or 5-and-10-cent stores. These will give you a start, but they will usually be over-priced. Your class may wish to pool its purchases and mix an economical quantity by the instructions of Chapter 2. Or perhaps the teacher will have on hand some small amounts to distribute at cost to get you started.

* * *

ASSIGNMENTS

Projects for beginners in soilless gardening

1. EXPLORATORY PROJECTS: Assignments in small-scale experimental set-ups.

- a. Provide a sand culture arrangement, possibly with wick watering, for sprouting seeds.
- b. Provide a continuous drip arrangement in conjunction with a sand or water culture arrangement for two tomato plants.
- c. Make or have made a box-and-bucket unit as described in Chapter 4.

2. A PROFITABLE PROJECT: A scheme by which you can make your special skill in small units pay off. Design, make, and sell indoor ornamental displays with chemical supplies for people wishing to undertake small-scale experimental soilless gardening.

EVALUATION

Some ways you can check your soilless gardening techniques for the purpose of improving them

1. TRUE-FALSE QUESTIONS: Answer the following questions by marking an X in the right parentheses, and have them checked.

- a. ^T(X) ^F() Tomatoes are a good plant for beginners to work with.
- b. () (X) Flowers are difficult to grow by soilless culture.
- c. () (X) Growing plants in sand makes air-supply to the roots unnecessary.
- d. (X) () Sand culture is easier to work with than pure solution culture.
- e. (X) () For good aeration you should avoid the finest grade of sand.
- f. () (X) Soilless plant culture is an expensive hobby for the beginner because he has to discard solutions after a week's use.
- g. (X) () The simplest method is to grow plants in sand in flower pots, catching the drained-off solution in a dish or can.
- h. (X) () Prepared mixtures sold in small packages are apt to be poor buys.

2. MULTIPLE CHOICE QUESTIONS: Write the letter corresponding to the best answer in the parentheses provided.

- () Plants do not have to have: (a) A supply of chemicals; (b) A supply of air to the roots; (c) Organic fertilizers (manure, leaf mold, etc.); (d) A means of support.

3. COMPLETION QUESTIONS: Write the missing word in the blank in front of the question.

- a. zinc Galvanized buckets, and any other articles similarly coated with (a) should be given a coating with
- b. asphalt (b) before putting solution in them.

CHAPTER 2. SOLUTIONS HOW TO FEED YOUR PLANTS

All systems of soilless gardening are alike in the one respect that they provide plant roots with the essential plant foods dissolved in water. You should study this chapter to learn how to combine the right amounts of the right chemicals in a water solution. Later in Chapters 6 and 7 you will learn how to change the amounts of chemicals or water to suit changes in weather conditions or the condition of plants. First you must learn how to follow directions, weigh chemicals and dissolve them in the right amounts of water.

A. COMPOUNDING SOLUTIONS How to prepare your own nutrient solutions

In cases where good mixtures of chemicals for soilless gardening are not available in retail quantities at reasonable prices, or if you want to learn the principles of compounding mixtures and preparing solutions, you should learn how to obtain the necessary chemicals, weigh them correctly and prepare the solution.

1. How to give your plants all needed chemical elements. Several combinations of our hydroponics elements are possible. The simplest to understand and the best for purposes of manipulating the composition would be made up entirely of acids and bases. We shall use this type in our deficiency experiments in Chapter 6. This makes it possible to include or leave out any element desired without affecting the others. Thus we use hydroxides or oxides of the metallic elements: KOH, $\text{Ca}(\text{OH})_2$, and MgO; and we use acids of the non-metals: HNO_3 , H_3PO_4 , and H_2SO_4 . This accounts for the six "major" elements, potassium

(chemical symbol K), calcium (Ca), magnesium (Mg), nitrogen (N), phosphorus (P), and sulfur (S). The five trace elements, iron (Fe), manganese (Mn), boron (B), zinc (Zn), and copper (Cu), could also be supplied in this way, but usually are not. Instead we supply iron in a separate solution, in the form of ferrous sulfate (FeSO_4), or other compounds of iron. The other four minor elements may be supplied in a single solution, such as described in Table I, on the next page.

2. How to prepare a formula composed of chemical salts. A formula prepared with chemical salts is more economical than one composed of acids and bases, since each chemical supplies two elements, instead of only one. The formulas given in Table II give you instructions on the preparation of several nutrient solutions. The purpose of presenting this variety is to allow you to choose one of them according to the availability of chemicals, the conditions of weather, and the type of water you have. These formulas are taken from Connors and Tiedjens, listed in the Reserve Shelf List, pages 83 and following. They enable you to prepare one to twenty-five gallons of solution.

3. How to obtain the needed chemicals. Only in scientific work is it advantageous to use distilled water and pure chemicals. For ordinary soilless gardening, chemicals of fertilizer grade are satisfactory, as well as technical chemicals which do not contain too much fluorine, selenium, arsenic, or lead as impurities. To avoid these impurities, use the technical grade of sulfuric acid, and specify "food grade" of ammonium phosphate or potassium phosphate.

In shopping for chemicals, buy small amounts (10 lbs. or less) at chemical supply houses and drug stores. In buying amounts of 25 to

TABLE I
SUPPLYING THE MINOR ELEMENTS

A. DIRECTIONS FOR SUPPLYING FOUR MINOR ELEMENTS

DISSOLVE:

Chemical	Amount
Manganese sulphate	1 gram
Boric acid	1.5 grams
Copper sulphate	.5 gram
Zinc sulphate	.5 gram
Water	1 quart

Add one tablespoonful to each gallon of nutrient solution.

B. DIRECTIONS FOR SUPPLYING IRON

DISSOLVE:

Ferrous sulphate	5 grams
Water	1 quart

Add one tablespoon to each gallon each time plants show pale or yellow appearance.

TABLE II
SUPPLYING THE MAJOR ELEMENTS
Some standard nutrient solutions (from Connors, p. 84 and following.)

CHEMICAL	SOLUTION A	
	AMOUNT	
	Grams	Tsps.
Primary potassium phosphate	2.3	$\frac{1}{2}$
Calcium nitrate	8.0	2
Magnesium sulphate	4.2	$1\frac{1}{2}$
Special solution (Table I, A)	14.5	3
Dissolve in one gallon of water.		

SOLUTION B

(This solution contains ammonium nitrogen, good for summer conditions. For winter, double or even triple the salts for the same amount of water, reduce or omit ammonium sulphate.)

Primary potassium phosphate	2.3	$\frac{1}{2}$
Calcium nitrate	8.0	2
Magnesium sulphate	4.2	$1\frac{1}{2}$
Ammonium sulphate	1.0	$\frac{1}{4}$
Special solution (Table I, A)	14.5	3
Dissolve in one gallon of water.		

SOLUTION C

(For summer conditions where tank culture is used for such plants as tomatoes.)

Primary potassium phosphate	5.0	1
Calcium nitrate	20.0	4
Magnesium sulphate	10.0	4
Ammonium sulphate	2.5	$\frac{1}{2}$
Special solution (Table I, A)	362.5	75 ($\frac{3}{4}$ pint)
Dissolve in 25 gallons of water.		

SOLUTION D

(For tank cultures. Special solution may be omitted, if advisable. Use fertilizer grade salts.)

Superphosphate 44%	6.0	$1\frac{1}{2}$
Sodium nitrate	4.0	1
Magnesium sulphate	6.0	$1\frac{1}{2}$
Muriate of potash	4.5	1
Ammonium sulphate	2.0	$\frac{1}{2}$
Special solution (Table I, A)	72.5	15
Dissolve in 5 gallons of water.		

TABLE II (Continued)

SOLUTION E

(Especially useful for alkaline sand or hard water.)

CHEMICAL	AMOUNT	
	Grams	Tsps.
Primary ammonium phosphate	3.0	2/3
Potassium nitrate	14.0	3
Calcium nitrate	15.0	3
Magnesium sulphate	8.0	2
Special solution (Table I, A)	72.5	15
Dissolve in 5 gallons of water.		

SOLUTION F

(For home experimentation in sprouting seedlings, or feeding plants in soil, etc.)

Saltpeter	1	1
Epsom salts		1
Baking powder free of alum		2
Washing ammonia (Concentration varies)	1 to 4	
Special solution		None
Dissolve in one gallon of water.		

100 lbs. of commonly used fertilizer chemicals, such as superphosphate and calcium sulfate, try fertilizer suppliers first, then chemical supply houses.

4. How to weigh or measure chemicals. If you do not have a chemical balance, you can use grocery scales for weighing one ounce or more, or have a druggist weigh up the chemicals. Especially in weighing up the minor element chemicals, the help of a druggist may be valuable. For the major elements, you may find it convenient to measure them instead of weighing them. The following facts may be useful in converting a formula from a weight basis to measurements: 1 lb. equals 454 grams. 1 liter equals .95 quart. 1 tablespoon equals 3 teaspoons, equals 14.5 cubic centimeters (milliliters). 1 gallon equals 3.78 liters, equals 4 quarts. A tablespoonful of calcium nitrate weighs 20 grams; of primary potassium phosphate, 18 grams; of magnesium sulphate, 12 grams; and of potassium nitrate, 13 grams. (From Connors, p. 193.)

5. How to dissolve the chemicals. For large-scale hydroponics Gericke suggests preparing a complete dry mixture, including the minor elements, to be sprinkled into the solution or onto the "seedbed" and washed down. Thus all the necessary elements can be supplied in one operation to last plants for two or three weeks, with the exception of iron. This must be "doled out" in smaller quantities about once a week, because more at one time may be harmful, and also because it disappears or precipitates from the solution.

Another method of adding chemicals to the solution is to dissolve each chemical separately and add it to the total solution carefully to avoid precipitation. Although this may be unimportant in large tank

cultures, it may be wise to follow this precaution in small sand culture or gravel culture projects.

B. ADJUSTING SOLUTIONS

How to control acidity, aeration, and temperature

Just as proper foods are necessary but not sufficient for human health, so a good chemical mixture of the right concentration is only one of the essentials for plant growth. You must maintain the correct degree of acidity of the solution; you must provide sufficient air to prevent stagnation of the solution, and you should also in some cases give thought to temperature and light conditions favorable to your plants.

1. How to maintain the proper range of acidity. Farmers favor a neutral or slightly alkaline soil, but in soilless gardening we favor a slightly acid solution. To maintain the correct acidity, test with an indicator, such as nitrazine test paper, and add sufficient acid or base to bring the "pH" (degree of acidity-alkalinity) to the desirable range of 5 to 6.5. To lower the pH, add sulfuric, nitric, or phosphoric acid. Usually sulfuric acid is used. The chemical formulas of the three acids are H_2SO_4 , HNO_3 , and H_3PO_4 . To raise the pH, which is seldom necessary, add a base, such as calcium hydroxide, $\text{Ca}(\text{OH})_2$, potassium hydroxide, KOH , or magnesium oxide, MgO .

We have called pH a measure of the "degree of acidity-alkalinity of a solution." Chemists have found that water contains "ions", or electrically charged particles. The positively charged ions are hydrogen atoms which have lost an electron, and are symbolized H^+ . The negatively charged electric particles are composed each of a hydro-

gen and an oxygen atom, with an extra electron, and symbolized OH^- . When an H^+ ion and an OH^- ion meet, they form a molecule of water, written HOH , or usually, H_2O , with no electric charge. Only a very small part of the water breaks up into these "ions". Thus in 1000 grams of water, only .0000018 grams of these "ions" will be found. Now the H^+ and OH^- ions are in balance, so that when either is increased a hundredfold, the other is decreased by dividing by the same number. When the numbers of each are equal, we say the solution is neutral (pH equals 7), neither acid nor basic. At the neutral point, the number of grams of H^+ ions in a liter of water is $1/10,000,000$ gram. Note the 7 zeroes. Any acid which we add to the solution will supply H^+ ions (that is what makes it an acid), making more H^+ ions, and thus fewer zeroes in our fraction, giving us a lower pH. In a slightly acid solution of pH 6, there will be $1/1,000,000$ grams of H^+ ions in a liter. This is a good degree of acidity for many plants. The favorable range for most plants is from pH 5 to pH 6.5.

The reason that pH is important, is that the solubility of iron, phosphorus, and manganese depends on the degree of acidity. In a neutral or alkaline solution, (pH 7 or more) the OH^- ions are so numerous that they combine with the iron and "lock it up" in the insoluble hydroxide form, and iron starvation of the plants results. If you see the growing tips of the plants turn pale or yellow, they need more iron than they are getting. You may not be adding enough iron, or your solution may not be acid enough.

2. How to maintain the desired degree of aeration. Stagnation of the solution is encouraged by: (a) too fine sand in sand culture,

or (b) formation of a thin oil film in hydroponics, or (c) lack of movement of the solution; and by other factors. To improve aeration of the solution, you may: (a) Use coarser sand in sand culture. (b) Do not let flooding by solution in gravel culture last too long (best not over 15 minutes). (c) "Blot" off oil film from solution surface by laying on a newspaper and thus absorbing film. (d) Permit solution level to drop in hydroponics until 3 or 4 inches of roots hang through moist air into the solution. (e) You may also bubble air into the solution with an aquarium aerator, or (f) Arrange an air intake into a centrifugal circulating pump, if used, or (g) Bubble air through the solution with a bicycle pump for 5 minutes a day, or (h) Use a continuous drip method with a funnel aerator, or (i) Practice gravel culture with sub-irrigation, which generally gives good aeration.

3. How to adjust temperature and light conditions. When growing plants in sand or gravel or solution, you may be making drastic changes in temperature or light conditions of which you may not be aware. This is what happened when Gericke first tried growing roses in hydroponics, with the result that the roses did not do well, because their stems were getting too hot from the sun's direct radiation combined with reflection from the light colored seed bed. When grown with chrysanthemums which partly shaded the rose stems, they began to do much better. Thus you see that hydroponics is not a "cure-all", and may produce troubles of its own. The best method to follow is to try various plants out on a small scale by various methods to discover which one gives the best results, and then you can use the best method

on a large scale.

One thing to notice, is that in soil growth, plant root temperatures change slowly, while the temperature of the tops changes quickly. While you may not necessarily have to duplicate these conditions for every kind of plant, in some cases this could cause trouble. Water has a high "specific heat"; that is, it is "reluctant" to change temperature, so a hydroponics tank 4 ft. by 10 ft. with 6 in. deep solution, covered by a 4 in. thick seed bed, will hold a more steady temperature than a 1 ft. wide tank with 3 or 4 in. of solution and a 2 or 3 in. thick litter. Much of the gravel culture practiced by the Army at Ascension and other islands and in Japan was done under a netting of cheese cloth to reduce the sun's direct radiation. Also most commercial soilless gardening is practiced in greenhouses where temperature conditions can be controlled by summer shading and winter heating. This does not mean that you will have to put up a greenhouse to carry on soilless gardening. But you should take some thought about temperature and light relations, especially if plants seem to be doing poorly. Some plants require lots of light; other plants need partial shade; other ornamental plants need full shade.

* * *

ASSIGNMENTS

Some projects in managing solutions.

1. EXPLORATORY PROJECTS: Some first steps in preparation of formulas and solutions.

- a. Check local garden supply stores for hydroponic chemicals; examine the stated contents and the price, and locate the best buy in your area.
- b. Obtain price quotations for the chemicals in one of the combinations of Table II, and compare the cost of mixing 100 lbs. in 5 lb. lots with the price in "a" above.
- c. Choose carefully the best formula adapted to your conditions of light, temperature, and water supply, and justify your choice to the class and your teacher.

2. PRODUCTIVE PROJECTS: Worthwhile undertakings in the preparation of formulas and solutions.

- a. If your investigations in "a" and "b" above reveal the need, carry out a cooperative class project of purchasing, weighing, mixing and packaging suitable amounts of plant food chemicals.
- b. Prepare a week's supply or other suitable quantity of plant nutrient solution, adjusting the pH correctly.

EVALUATION

Some tests to apply to your skill
in managing solutions

1. TRUE-FALSE: Place an X in the proper parentheses preceding each question:

- | | | | |
|----|-----|-----|---|
| | T | F | |
| a. | () | (X) | Although the 6 major and 5 minor chemicals are best, others may be substituted for some of them. |
| b. | () | (X) | A formula composed of acids and bases is the most economical one. |
| c. | (X) | () | You should choose an acid and base formula if you wish to provide one essential element with each chemical. |

- d. (X) () You should maintain the pH at 5, if you wish to furnish 10,000 times as many H as OH^- ions.
- e. (X) () You should adopt a formula containing salts, like potassium nitrate, KNO_3 , if you desire to supply the essential plant food elements in pairs.
- f. (X) () Although plants use 14 elements, you need to provide only 11 through chemicals.
- g. () (X) Nutrient solutions should be more dilute in winter than in summer.
- h. (X) () You should maintain the strength of your solution between about 1500 parts per million and 3,000 p. p. m.
- i. (X) () To convert a solution strength of .2% by weight to "parts per million", you must multiply by 10,000, obtaining 2,000 p. p. m.

2. BEST ANSWER: Give the answers required in a, b, c, and d, below, concerning the following 22 chemical elements:

- | | | |
|--------------------|---------------------|-------------------|
| (1) nitrogen (N) | (9) magnesium (Mg) | (17) boron (B) |
| (2) sodium (Na) | (10) lead (Pb) | (18) cobalt (Co) |
| (3) potassium (K) | (11) sulfur (S) | (19) copper (Cu) |
| (4) chlorine (Cl) | (12) fluorine (F) | (20) silicon (Si) |
| (5) phosphorus (P) | (13) iron (Fe) | (21) zinc (Zn) |
| (6) arsenic (As) | (14) silver (Ag) | (22) iodine (I) |
| (7) calcium (Ca) | (15) manganese (Mn) | |
| (8) selenium (Se) | (16) carbon (C) | |

- a. Write the numbers of the 11 elements which you must furnish

- to your plants in solution. (Ans. 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21.)
- b. Write the numbers corresponding to the elements which should be avoided, even in small amounts (poisons). (Ans. 6, 8, 10, 12.)
- c. Write the numbers of the elements which must be added quite often: about once a week. (Ans. 13.)
- d. Write the numbers of 5 elements which must be supplied, but are poisonous or harmful if too much is used. (Ans. 13, 15, 17, 19, 21.)

SOURCES

Where to find more instructions on formulas and solutions

1. BOOKS: Reserve Shelf Citations: Connors, 79-89; Ellis, 129-154; Gericke, 43-63, 64-74; Spessard, 32-8, 100-10, 122-5; Turner, 36-73. See also the other sources in the Bibliography.
2. MAGAZINES: Short popular articles containing material on formulas and solutions: See Magazine references Nos. 24, 29, and 30.
3. ENCYCLOPEDIA: Encyclopedia articles giving help on this subject: The Encyclopedia Americana article, "Hydroponics."

PART II. DEVELOPING YOUR METHOD

HOW TO GROW PLANTS IN SAND, GRAVEL AND WATER CULTURE

Assuming that by one means or another, you have gotten something started growing in nutrient solution and sand, gravel, or possibly water, you can take time to consider ways and means of improving or enlarging the project you have started. This section will describe the techniques involved in sand culture, gravel culture, and water culture, so that you can undertake something on a little more ambitious scale. Each type of medium has certain advantages, and certain problems peculiar to it. Sand culture is said to be the easiest for amateurs to practice, since it is the smallest departure from soil culture. Next in complexity is gravel culture, which has had perhaps the widest commercial application. Finally, in hydroponics, or pure solution culture, we have the most radical departure from soil culture, with certain advantages and certain problems peculiar to it alone. You will be wise to study this section carefully, to aid you in expanding or refining your practice of soilless gardening.

CHAPTER 3. SAND CULTURE

HOW TO GROW PLANTS IN INERT FINE MATERIALS

Growing plants in coarse sand with chemicals is the least radical departure from agriculture, and perhaps the easiest method for the amateur to undertake. Plants are supported by their own roots as in soil, hence need not be suspended on a rack as in hydroponics. Containers need not be water-proofed for a drip culture method, as they must be in gravel and water culture; or again, they may be if you wish to re-use the solution. A drip culture requires little attention and can give good results. However, the more skillful you become, the better results you can expect.

A. THE BASIN

How to accomodate the plant roots

You will put your sand in some basin, box, pot, or receptacle, or in a shallow bed in the ground, and here you will grow your plants and feed them with nutrient solution. The receptacle is not critical, but a few points may need to be stressed.

1. How to provide drainage. In sand culture you must guard against keeping the roots too wet, and so depriving them of sufficient air. Choose sand coarse enough that it does not remain soggy, and provide adequate drainage. Cut holes in the bottoms of cans, or pans. Make holes in boxes or trays, sloping down to the hole, and covering the hole with a flat bit of tile. Likewise place gravel in the bottom of flower-pots and cover the hole with tile. You may have a sand bed

in loose porous soil, but in muddy soil you must provide a drainage trench to prevent soggy conditions. In a Spessard type hydroponicum, (see Spessard's book) a drainage trench is provided at one side of the concrete flat tottomed basin to drain the bed of sand which is watered from the opposite side. Otherwise, this type of basin is quite similar to those we shall describe in the following chapter.

2. How to avoid toxic materials. You should not permit plant roots to come in contact with zinc, as this is toxic to plants. Coat all galvanized buckets and tubs with asphalt (not tar) paing, whether they are to be used for growing plants or preparing solution. Copper is also toxic, but small amounts of copper or brass tubing will not contaminate the solution, since copper is chemically less active than zinc. For safety, coat the insides of tin cans also, although they have been used with no ill effects. A newly built concrete basin should be given three or four weeks to age, and should then be soaked with water to leach out alkaline compounds. These are also sometimes coated with asphalt paint, to minimize the chemical interference of the cement with the solution chemicals.

B. IRRIGATION

How to supply nutrient solution and water

Perhaps the most important phase of sand culture, or any soilless culture, is providing the plants with food and water. Chapter 2 has given you the principles of preparing solutions. Now you will have to go through the routine steps of mixing and applying the solution to the sand in which your plants are growing.

1. How to prepare the solution. Prepare a quantity of solution that will be economical of your time. This means your solution should last at least a week, perhaps a month, if your projects are small. In the Spessard system of sand culture, the solution is prepared daily, but that is not as much trouble as you might think, since quantities are measured out with a tin can, rather than weighed. You too, may adopt teaspoon or cup measurements after converting the formula to this basis. In constructing a large sand-culture project, similar to the Spessard units, you may build a permanent concrete tank or use a barrel or oil drum.

2. How to treat the sand. If you choose ordinary river or plastering sand, it will probably contain enough limestone to influence the pH of your solution toward the alkaline side of neutrality. You can check this by saturating the sand with somewhat acid solution, then checking the pH after 10 or 15 minutes. Sand containing lime should be soaked in superphosphate solution or weak phosphoric acid, after which it will not appreciably affect the pH. This is due to a thin coating of insoluble calcium phosphate, Ca_5PO_4 , which forms over the calcareous sand particles.

3. How to apply the solution. Wet the sand with the solution once a day on the average, but oftener in hot weather, less often in cloudy, cool weather. In rainy weather the plants may be deprived of their chemical food, and you may have to sprinkle a little 15-30-15 commercial fertilizer on top of the sand, to be dissolved by the rain. In ordinary weather, it would be best to avoid wetting the top of the sand, especially with lettuce, melons and squash, which are sensitive to

moist conditions.

If chemical salts seem to form a crust on top of the sand, wet with plain water in place of your solution. It is best to acidify your water to the right pH, if you have hard alkaline water. In any case, you should flush the sand with water about once a week, especially if the formula contains "filler" elements, such as sodium and chlorine. These tend to accumulate to an undesirable point if not flushed out.

C. CARE OF PLANTS

How to vary conditions to keep plants thriving

In soilless as well as soil gardening, much depends on the skill with which you notice how your plants react to the changes in their treatment. The more care you take the better results you should be able to get. Following are some steps to take in caring for plants.

1. How to start young plants. If you are in a hurry, you may buy started plants from a nursery, but it will be more economical and more fun to grow them from seed. Plant seeds in a standard seed flat filled with sand. Keep it wet until seeds sprout, then wet with 1/5 strength nutrient solution, gradually increasing the concentration as the plants grow. When 2 in. tall, transfer to the sand bed, pulling them out gently while pouring on water to loosen the sand from the roots. This preserves the most roots. Set the plants in the sand bed, giving the roots plenty of room.

2. How to support plants. Tall plants may need extra support from being tied to poles or wires, since the sand is soft and yielding. Sometimes corn plants are held in place by growing them through a rack of 2 in. mesh chicken wire netting, which is then firmly held

in place by a frame.

3. How to adjust to hot bright weather. In summer weather, the root zone may become too warm for the health of plants. The sand or the whole plants may be covered with netting to give partial shade. This method is used in tropical soilless gardening establishments. The solution should be more diluted, and extra amounts of nitrogen should be given, perhaps in the form of ammonium nitrate. (See Formulas 8, 9, and 10 in Spessard's book.) Also plants use less potassium in summer weather. See Chapter 6.

4. How to adjust to cool cloudy conditions. With less light, plants make less sugar and therefore grow less rapidly. If excess nitrogen is present, growth proceeds but is too soft and succulent for the good of the plant. More potassium should be supplied, as this results in more hardy growth, preparing the plant for colder weather. Also a more concentrated solution reduces the water intake.

5. How to choose the best plants. The best plants for sand culture will be tomatoes, beans, onions, and other plants which are not susceptible to moist surface conditions. However, a layer of gravel or water repellent mulch (straw, lawn clippings, peanut shells) on top of the sand will help in growing plants like lettuce which are affected by wet surface conditions.

* * *

ASSIGNMENTS

Some projects in the sand culture
method of soilless gardening

1. EXPLORATORY PROJECTS: Learning activities for beginners: Feed

nutrient solution to vegetable and flower plants growing in sand in pots, cans, boxes, trays or sandy beds in the ground.

2. PRODUCTIVE PROJECTS: Profitable serious undertakings in the sand culture method of soilless gardening.

- a. Construct and operate a Spessard type hydroponicum to raise vegetables for your own use and sell to local stores.
- b. Convert your greenhouse from soil to sand culture.

EVALUATION

Some means of checking and improving
your sand culture techniques

1. PAPER AND PENCIL: Place X's in the proper parentheses before these true-false questions:

- a. (X) () If the solution persistently tends to become alkaline when applied to a bed of river sand, you should soak it with a phosphate solution.
- b. (X) () If sand packs and stays wet when drained, you should choose a coarser grade.
- c. (X) () The tops of such plants as lettuce and cantaloups should be protected from contact with wet sand.

2. ADVICE: Take advantage of others' help.

- a. Have fellow students and the instructor examine your projects and give you pointers.
- b. Have your plans for a Spessard hydroponicum carefully checked before you begin construction.

SOURCES

Materials to aid you in studying sand culture

1. READING: Reserve Shelf Books: Connors, 96-103, 111-126; Ellis, 27-9, 61-84; Geriche, 248-56; Laurie, 114-27; Spessard, 15-31.
2. VISITS: Make field trips to such places as: Chemiculture Company, Montebello, E.R.Brundin, owner, where roses are grown in sand culture.

CHAPTER 4. GRAVEL CULTURE

HOW TO GROW PLANTS ROOTED IN COARSE INERT MATERIALS

You may, or may not, someday grow plants in a commercial hydroponicum by the method of gravel culture. Even if you do not, it will pay you to become familiar with the details of this method, since it is the method most widely used commercially, and its adoption solves a good many common problems found in soilless gardening. Even in your home projects, you could adopt the essential features of the method without installing expensive pumps, time clocks, and piping.

A. THE LAYOUT

How to build the essential structures

The essential elements in gravel culture are the gravel beds, the solution tanks and drainage sumps, and the pumps and piping, or flumes. (A fine description of gravel culture will be found in Ellis and Swaney's book. See the RESERVE SHELF reference at the end of this chapter.)

1. How to lay out the gravel beds. The following is a common plan of construction. The beds are $2\frac{1}{2}$ to 5 ft. wide, with a shallow V bottom, sloping 1 or 2 in. from sides to center. The sides are 7 or 8 in. high. In the center is laid an inverted tile or trough to provide alternate irrigation and drainage. The solution seeps out and in under the tile and through the joints. The beds may be any convenient length, up to about 150 ft. in some cases. They should slope lengthwise 1 to 4 in. in 100 ft. of length to provide quick drainage. (See

Ellis, illustration p.100.)

For cheapest construction, beds may be scooped out in the ground and lined with composition sand-and-asphalt 1 to 2 in. thick, mopped with hot asphalt. (See Ellis, illustration p. 41.) More convenient to work at are raised beds of wood or reinforced concrete, which must be well supported to stand the weight of the gravel and plants. All kinds of beds should be coated with asphalt, applied hot, or as a paint dissolved in gasoline or naphtha, or in a water emulsion. The asphalt protects the solution from contamination by cement chemicals, and improves the waterproofing.

2. How to provide adequate solution and drainage tanks. The solution tanks should have a capacity varying from the same to double the solution capacity of the growing beds filled with gravel. You may assume the gravel will occupy about half the volume of the beds, and the solution the other half, when filled. Thus, the volume of the tanks should be from one half up to the same as the gravel beds, for best results. If you have the tanks smaller than this, your labor of testing and replacing used chemical plant foods will be increased, since you will have to do it oftener. Cement tanks should be coated with asphalt in the same way as the growing beds.

3. How to provide proper pumps and piping or flumes. For best results provide for complete filling and emptying of the beds in five to ten minutes, but not more than about a half hour. Longer than this interferes with proper aeration of the roots and the plants will suffer. Choose the capacity of your pump to provide this rapid filling if you

pump directly into the beds. If you have a raised tank and fill the beds by gravity flow, the capacity of the pump can be much smaller. For safety's sake, you should have a stand-by gasoline power pump in case your electric powered pump breaks down. Your pump will, of course, be connected by 2 or 3 in. piping from the drain sump to the overhead solution tanks. The irrigation of the beds may be accomplished by a flume system or by piping. (See the book by Ellis and Swaney, diagrams on pages 102, 106, and 109, and the accompanying descriptions in the text.)

Some pumps are controlled by automatic time clocks, but just as good results or better can be had by manual operation. For information see the above book by Ellis and Swaney, p. 123.

B. OPERATION

How to grow plants successfully

Different crop plants have varying requirements for solution acidity, composition, and temperature, light and moisture conditions, but a few hints of a general nature may be given. The directions given in the previous chapter on sand culture will apply here also, with allowances for the difference in the medium. (The gravel and sand are referred to as the medium.)

1. How to adjust to varying weather conditions. Hot, bright, summer weather conditions will require more frequent pumping of the solution through the beds, to provide plants with sufficient water. The solution can be somewhat diluted under these conditions, but the

more frequent pumping has a similar effect. In cool, cloudy weather, on the other hand, the solution may be pumped at 48 hour intervals. Since the solution film on the gravel dries slightly, this has the effect of thickening the solution, or making it more concentrated. This has the effect on the plants of hardening them in preparation for winter conditions. The same suggestions on decreasing nitrogen and increasing potassium supply in cool weather and reversing this in hot weather apply here that were made in the last chapter.

2. How to seed and transplant. Plant the seed a little deeper in the gravel than you would in sand or soil. Or you may start the plants in a seed flat in sand or soil and transplant them when they are two to four inches high. You may remove the soil or leave it attached to the roots. Under tropical conditions and perhaps in some situations here, you will have to protect the seed from birds, and sometimes from ants which will dig it out.

3. How to select suitable gravel. Avoid gravel with too sharp edges, such as crushed granite or hard rock. The sharp edges may damage the roots, or shred the tender lower leaves of lettuce. Gravel from river beds or seashore should be satisfactory. The same instructions regarding calcareous sand apply to gravel. Soak it with treble superphosphate until chemical tests show that the phosphate content of the solution is not decreasing. This means that a coating of calcium phosphate has been formed on the surface of the gravel particles. The remaining phosphate solution should be saved to make your nutrient solution. Other materials besides gravel may be used, such as cinders,

(properly treated to overcome alkalinity or acidity), Haydite, expanded vermiculite, etc. Avoid soft decomposable materials which will have to be replaced when they disintegrate.

You should keep the surface of the gravel bed dry. A wet surface promotes the growth of algae and of fungous diseases of the lower plant parts. You can accomplish this by filling the beds only to an inch below the surface of the gravel, then draining.

C. HOME UNITS

How to carry on gravel culture in your back yard

The advantages of the gravel culture method in providing air to the roots and support for the plants are sufficient for you to try them out in your home production units. This section will tell you how you can modify the construction and operation to fit your needs.

1. How to construct home units. A good design for home use is the "bucket-and-gravity" type of unit, shown in Figure 3. (See also Ellis, p. 91, and accompanying description.) This consists of a waterproof tray or box with drainage outlet, which is connected by a rubber hose to the bottom of a bucket containing the solution. The raising and lowering of the bucket irrigates and drains the gravel tray. The buckets may be of ordinary galvanized 3 gallon size, with a half-inch black iron nipple soldered or welded in the side of the bottom. The box or tray should be coated with asphalt and the nipple installed in the end or bottom. The bucket should hold enough solution to wet the gravel within an inch or half-inch of the surface. Of course, you will also need a

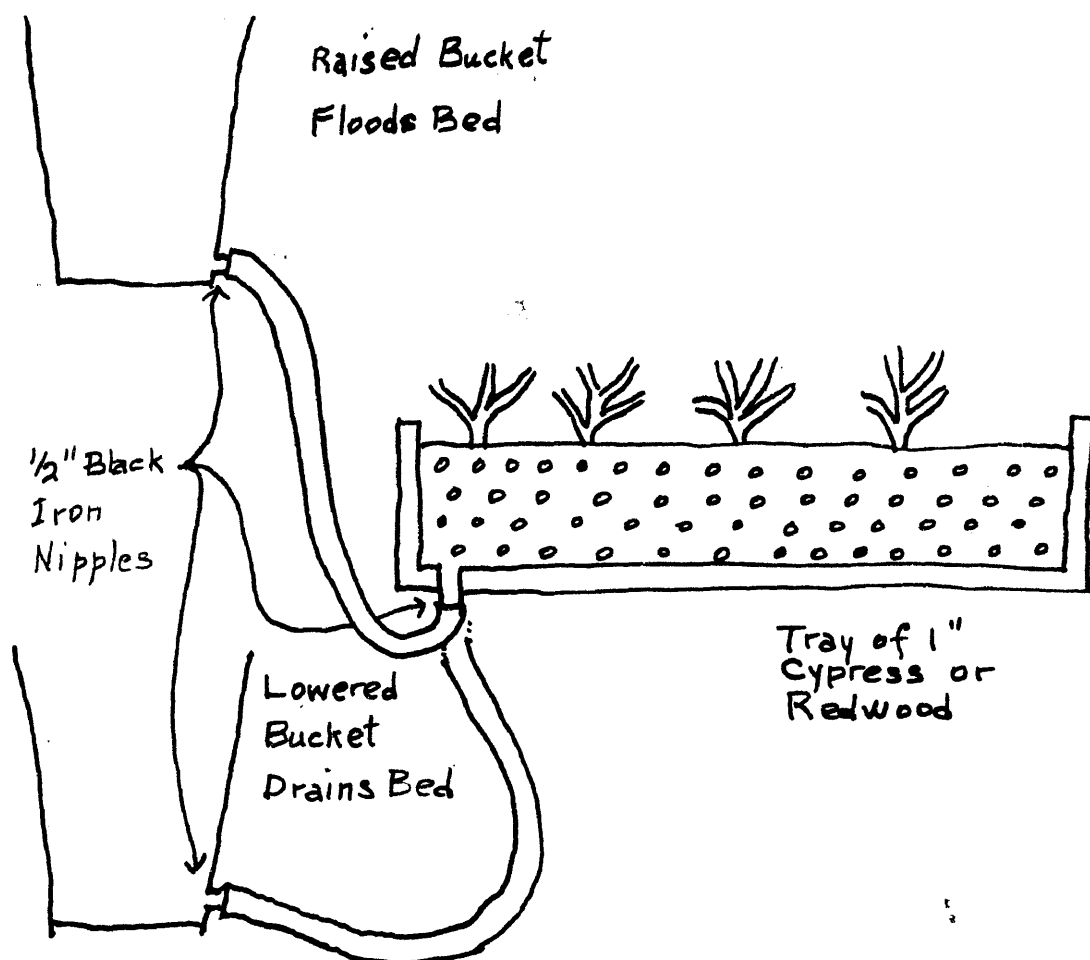


FIGURE 3
BUCKET-AND-BOX UNIT

tank or barrel for preparing your chemical solution. Any cement or metal container had best be coated with asphalt. A wooden barrel, if clean, may be used without coating.

2. How to grow plants in home units. Follow the same general suggestions for large capacity commercial units. The advantage of operating four to a dozen bucket-and-gravity units in your back yard is that you can vary the solution composition or concentration between the units and compare the results, then give all the units the conditions you have found to be the best. Thus you could vary the dilution until you discovered the best, then vary the nitrogen content of the solution, and so on. Thus a multiple bucket-and-gravity layout is ideal for the amateur undertaking soilless gardening in his back yard.

* * *

ASSIGNMENTS

Some projects in the gravel culture
system of soilless gardening

1. EXPLORATORY "PILOT PLANT" PROJECTS: Learning activities for amateurs.

- a. Construct a bucket-and-box unit of gravel culture and grow flowers and vegetables.
- b. Draw up plans with estimated costs for constructing twenty bucket-and-gravity units for home production.
- c. Draw up plans with estimated costs for constructing 30 compressed air units as shown in Ellis, illustration on p. 97 or 98.
- d. Draw up plans with estimated costs of construction of a large

scale commercial gravel culture establishment with pumps, solution reservoirs, etc. Estimate operation, maintenance, and labor costs.

2. PRODUCTIVE PROJECTS: Profitable undertakings in gravel culture.

- a. Construct and operate enough bucket-and-gravity units to supply your family with vegetables, strawberries, and flowers.
- b. Carry out one of the plans worked out in b, c, d above and operate it as a business venture.

EVALUATION

Some means of checking and improving your techniques

1. ADVICE: Securing the help of others: Have your instructor or fellow students examine your "Exploratory Project" and give you tips on improving it.

2. RECORDS: Profit by your own experience: Keep careful records of the operation of your "Productive Project" and discover where you can (a) save in operating expense, (b) save in maintenance or prevent deterioration, (c) increase yield, and (d) increase income.

3. PAPER AND PENCIL TESTS: Answer questions like the following, and have them checked:

- a. () (X) To increase aeration, you should irrigate oftener.
- b. (X) () To harden plants, as in cool weather, you should pump less often.
- c. (X) () You should fill and drain the beds in 10 minutes or less.

SOURCES

Materials to aid you in studying water culture

READING: Reserve Shelf Books: Connors, 103-10; Ellis, 29-44, 85-128,
174-82; Gericke, 248-256; Laurie, 135-68.

CHAPTER 5. WATER CULTURE

HOW TO GROW PLANTS SUSPENDED OVER SOLUTIONS

In using the water culture method, or "Hydroponics" in the strict use of the word, we dispense with sand or gravel and give the roots their food in the nutrient solution in a shallow tank. Since water does not provide support, we root the plants in a bed of "litter": shavings, lawn clippings, straw, corn stalks, or other material, supported on a tightly stretched rack of chicken wire netting. In Gericke's system of operation, the chemicals are mixed in the dry form and sprinkled into the tank, where they gradually dissolve and spread through the tank to the plant roots. Thus a dissolving tank may be dispensed with.

So you can see that water culture may be carried on with a minimum of expensive equipment. On the other hand, it probably takes more skill to carry on this system of soilless gardening, since the aeration of the roots may become poor, unless the solution level is gradually dropped to provide an air space, or the solution is frothed up or bubbled with air every day. If you become skilled at reading your plants' wants by their appearance, and adjusting conditions accordingly, you may find this method the best one to adopt. It has given high yields in the hands of experts.

A. CONSTRUCTION

How to build basins and seed beds

Since the basin and the seed bed are your main items of equipment,

it is best to choose better materials and have them last longer than to make them cheaply and have them wear out before their time. The basin needs to be waterproof and durable. A poorly constructed seed bed will sag permitting the water to touch the litter. You should prevent these conditions by good planning and careful construction.

1. How to construct the basins. Basins should be 2 to 6 ft. wide, and any convenient length, say 10 to 50 ft., and should provide for 5 to 7 in. of solution depth. They may be made of wood, sheet metal, or concrete. Wood basins may be made of cypress or redwood, or other non-warping lumber, drawn together tightly with tie rods so that they do not leak. Gericke, p.28 shows one such tank made of 2 in. planking. This was more substantial than necessary. The tank may be made of 1 in. lumber and lined with building paper, mopped with hot asphalt, lined again and mopped with one more coat. When made of sheet metal, the sides may be turned up in a brake and the corners lapped and welded. Avoid galvanized iron, and coat with asphalt paint or emulsion before using. Concrete basins, if not coated with asphalt, should at least be leached for more than a week before use. Check chemically whether the solution pH is affected by the cement, and soak some more until it is not. The best practice is to coat with asphalt paint or emulsion.

2. How to construct the seed bed. The seed bed consists of a frame of 1x4 in. lumber braced crosswise every two feet. Over this is stretched tightly a net of 2 in. mesh chicken wire, which is then coated with asphalt paint. This rack rests on top of the solution tank, and is covered with 2 to 4 in. of "litter". The first step is to spread on

a layer of water-soaked excelsior, or possibly straw, to keep other material from falling through the wire netting into the tank. Then add more, possibly finer materials, until the litter depth is 2 to 4 inches, as desired. Potatoes require 4 inches, while lettuce requires a shallow seed bed.

You should provide a removable small section of seed bed to give you access to the solution so you can remove some for testing. Or the seed bed may be made in several sections and various crops grown in different sections, with varying litter depth in them. All the litter must be thick enough to produce darkness in the solution below. This prevents growth of algae and stagnant condition of the water.

B. MANAGEMENT

How to use your equipment efficiently

Some very high yields have been reported through the operation of water culture soilless gardening, or "hydroponics", but many authorities believe that this takes unusual skill and good management. Gericke is the chief exponent of this method. Following are some tips given by him and other authorities.

1. How to start plants. Plants may be transplanted into the seed bed, but it will be less labor to start them in the seed bed itself. Sprinkle the surface of the seed bed and keep it moist until the seeds sprout. Then sprinkle around the plants with solution to encourage the development of lateral roots in the seed bed. These serve to support the plants.

2. How to induce roots to grow downward into the solution. Keep

the solution level up within a half-inch of the wire netting. The roots will usually grow across this expanse of air. When the roots are well established, gradually permit the solution level to recede, increasing the air space finally to about three inches, with the water depth three inches also. An alternative procedure, especially when you have plants at various stages of growth over the same basin, is to shim up one section of seed bed to give the increased air space, leaving another section down, close to the solution surface.

3. How to adapt to temperature and light conditions. For some crops, such as potatoes, it is important to keep the solution temperature steady, and not let it rise much during the day. This is accomplished by having a deep seed bed, say 4 inches, and thick growth to provide shading. Also a wider and deeper basin will keep the root temperature more stable than shallower solution and narrower basins. The climatic factors were found by Gericke to be quite important. Roses grew better when partially shaded by chrysanthemums with which they were growing than when grown by themselves.

4. How to produce the greatest yields. Gericke is the only worker who reports on the use of multiple or overlapping crops; that is, starting one crop before another is harvested. In bright summer conditions, considerably more light is available than can be utilized by crops growing in soil. But in water culture, plants can be grown close enough together to make maximum use of the available light. In other words, the greater availability of nutrients makes light the limiting factor. He reported success in combining crops of potatoes, and

corn, potatoes, tomatoes and celery, two crops of potatoes, and corn, beans and potatoes. In all cases he reported better than average soil yield for each one of the crops. It may be that no other system of soil-less gardening can compete with water culture at this point. There is some evidence that roots of plants are toxic to other roots in sand culture, but not in water culture. Whether or not this is confirmed, the successful experiments referred to above should encourage the person who wants to make the maximum use of a limited amount of space in growing vegetables and flowers during the summer to adopt the water culture system.

5. How to provide proper aeration of roots. The practice of permitting the solution to recede gradually, thus increasing the air space, aids in aeration of the root system. Care should be taken not to refill the solution to the former high level, as this harms the roots. As other authorities are somewhat doubtful that this will provide sufficient aeration, however, it may be well to mention other methods to be used in addition. The water which is added to the tank may be forcefully sprayed in so as to aerate the solution daily. Or if a float valve is used, the outlet may be connected to a fine jet nozzle. Other suggestions are to whip the surface of the solution with a wire beater, pump air into it with a bicycle pump, or use a small aquarium pump to aerate the solution. It is stated that too much air can be provided, so some caution should be exercised.

* * *

ASSIGNMENTS
Projects in the hydroponic method
of soilless gardening

1. EXPLORATORY PROJECTS: Experiments and techniques for "feeling your way" into tank culture production.

- a. Grow several tomato, canna, or gladiolus plants with roots in gallon jars of solution.
- b. Operate a single Gericke type basin and grow some commercial crop.
- c. Keep accurate records on project "b", and prepare an estimate of the investment costs, operating, maintenance, and labor costs, and probably profits, of a full-scale project on a half-acre of ground.

2. PRODUCTIVE PROJECTS: Serious endeavors in tank culture.

- a. Construct and operate a Gericke type hydroponicum of 100 or 200 sq. ft. area to provide vegetables and flowers for your family and some to sell.
- b. Launch a business venture in soilless gardening, first doing Exploratory Projects "b" and "c".

EVALUATION
Checking of your water culture
techniques for improvement

1. ADVICE: Profit by help others can give you: Get other students and the instructor to check your water culture projects and offer suggestions for improvement.
2. OBSERVATION: Modify your procedures as you learn by experience:

Examine and observe the appearance, growth and development of your plants as affected by the methods you apply. Keep successful methods and discard unsuccessful techniques.

3. RESEARCH: Keep up to date on new developments: Continue to glean suggestions for improvement from experienced hydroponicum operators and plant scientists.

4. PAPER AND PENCIL: Answer and be checked on objective tests like the following: Place an X in the proper parentheses:

- a. (X) () Brown, poorly developed roots mean you should improve the aeration.
- b. (X) () After roots are established in the solution, you should allow the solution level to drop to 3 or 4 in. below the seed bed.
- c. (X) () According to Gericke, you should maintain the concentration from 500 to 1500 parts per million.

SOURCES

Materials to help you in the study of water culture

READING: Reserve Shelf Books: Connors, 89-95; Ellis, 22-26, 45-60; Gericke, 14-42, 75-107, 124-228; Laurie, 128-34; Spessard, 1-14.

PART III. SKILLFUL MANAGEMENT
HOW TO OPERATE YOUR SOILLESS GARDEN EFFICIENTLY

Although plants are called the "simplest" form of life, their growth and fruiting are not as simple as one might think. Perhaps you have discovered that by this time. But do not be discouraged by difficulties or occasional failures. Any attempt to do things in a new and better way is likely to show up the need for more fundamental knowledge and increased skill. Thomas Edison tried many kinds of filaments in his electric light before he found one that would work. Many people tried to fly before the Wright brothers hit on the right combination. It will be the purpose of the following section of this course to help you with difficulties, develop short cuts, and work out improvements in your methods of soilless gardening, so as to make possible really good results.

CHAPTER 6. DIAGNOSIS HOW TO CORRECT "UNHAPPY" PLANTS

Just as people or animals show signs of disease or deficiencies, so also plants very clearly react to lack or over-supply of the elements necessary for plant growth. Whether you garden in soil or solution, you will want to know the appearance of plants when they are in trouble and when they are doing well. In soilless gardening the appearances of plants may prompt you to make plant tissue tests or solution tests and to bring the solution ingredients back to normal. Study the information in this chapter and the visual aids available to gain skill in correcting plant deficiencies.

A. SYMPTOMS How to gain skill in diagnosis

A skillful farmer watches the appearance of his plants and notes signs of disease, pests, lack of moisture, or poor soil conditions. In soilless gardening also, you can save time and labor by anticipating the needs of your plants by skill in reading their appearance.

1. How to profit by the experience of others. In order to study the effects on plants of the lack of various elements, scientists have grown thousands of plants in special solutions which were lacking in these elements. Instead of repeating this research yourself, you should take advantage of their findings to help you spot the first signs of depletion in your chemical solutions. Table III on the following page has been prepared to give a brief summary of some of these facts. Word descriptions of these effects are helpful, but are not enough. You

TABLE III
SOURCES, FUNCTIONS, AND PRACTICAL FACTS ABOUT
PLANT ELEMENTS, LIGHT AND TEMPERATURE

ELEMENTS	SOURCE	FUNCTION IN PLANT	REMARKS
Carbon C	Less than 1% in air, only source.	Building material of tissues. No life without carbon.	Sometimes supplied under high light, cool conditions in green- houses. Costly.
Hydrogen H	In water, acids, bases.	Part of fluid. H ions acidify; OH ions alkalize.	Supplied in the water of your solution.
Oxygen O	From air, of chief impor- tance. Also water.	Releases energy of fuel substances. Important for roots.	Often lacking in water culture, sometimes in sand. Roots turn brown, fail to grow.
Nitrogen N	Air to bacter- ia to nitrates. Fertilizers. Chemicals.	Needed for growth. Lack causes storage of sugars. Too much depletes sugars.	Supply by nitrates. Am- monium also, in strong light conditions. Dark weather, reduce amount.
Phosphorus P	Phosphate rock. Phos- phates.	Needed for growth. Enables plant to use sugar.	Keep solution acid to keep soluble. Too much interferes with iron, calcium intake.
Calcium Ca	Lime, lime soils. Cal- cium compounds.	Forms cell walls. Important for root growth. Controls acidity.	Deficient in many diets. Too much interferes with phosphorus intake.
Potassium K	Wood ashes. Potassium compounds.	Compensates for dark conditions. Growth of stem tips, healing. Mobility of iron.	Increase supply in dark weather.
Magnesium Mg	Present in most soils. Magnesium compounds.	Ingredient of green chlorophyll of plants.	Used up in green tis- sue production.
Iron Fe	Locked up in basic or phos- phate soils. Iron compounds.	Needed to make chlorophyll.	Keep solution acid, phosphate supply moderate; add small amounts weekly.

TABLE III (Cont.)

ELEMENTS	SOURCE	FUNCTION IN PLANT	REMARKS
Manganese Mn	Some soils deficient. Very small amounts needed.	Expedites chemical reactions in the plant (catalyst). Too much toxic.	May be present in fertilizer grade chemicals. Study pictures of deficient plants.
Boron B	Some soils deficient. Very small amounts needed.	Catalyst. Lack kills growing tip of plant. Too much toxic.	May be present in chemicals or water supply. Study deficiency pictures.
Zinc Zn	Some soils deficient. Very small amounts needed.	Catalyst. Too much toxic.	May be present in chemicals or water supply. Study deficiency pictures.
Copper Cu	Some peat soils deficient. Minute amounts sufficient.	Catalyst. Aids in making chlorophyll. Too much toxic.	May be present in chemicals. Study deficiency pictures.
Molybdenum Mo	Less is needed than of any trace element.	Catalyst. Needed for setting of fruit.	Last to be discovered. (See Encyclopedia Americana, "Hydroponics".) If blossoms drop, check.
Light (Not an element)	Sun's rays. Long (heat rays) and short (ultra-violet).	Light energy stored in the form of sugar, starch, seeds in plant.	Choose sunny location for vegetables. Artificial lighting costly, but small amounts sufficient to change blooming season of some flowers.
Warmth (Not an element)	Sun's long rays warm earth, air.	Warm temperatures speed up chemical processes. Above 80-90, breakdown keeps up with build-up.	Root-top gradient, reversal at night, important for some plants. Different plants need different climates.

should see pictures, in color if possible, of plants which are affected by chemical deficiencies. A good procedure will be to study the book edited by Hambidge, "Hunger Signs in Crops", which we cite at the end of this chapter. It contains many pictures, in color and black and white, showing the effects of chemical malnutrition of various plants. You will do well to study the pictures carefully, not only of the particular plants you are interested in, but others also. Better still, if one or more of the films listed at the end of the chapter are available, obtain and show them and become familiar with deficiency symptoms, especially of the species of plants you are most interested in.

2. How to gain direct experience in diagnosis. Studying pictures and movies is a good start, but you will want to get more direct experience also. Don't carry on elaborate experiments. The class can organize an experiment, mixing the various compositions lacking in the particular elements. Choose some fast-growing, small plant which reacts sharply to deficiencies. Radishes would seem to be a good choice. (See p. 181 of the book we mentioned.) Observe carefully the appearance of the various plants grown in this way. Have your fellow students drill you on your ability to spot the lacking elements by the appearance of the plants, until you seldom make a mistake.

Now, in your soilless project at home or in class, you can keep a few radishes growing to aid you in correcting nutrient solution deficiencies promptly. By keeping the radishes looking well, you will also keep your tomatoes or other plants in good condition. Be sure to include solutions deficient in iron in these experiments, since appearance is the standard method of judging the lack of this element.

3. How to organize deficiency experiments. For simplicity we suggest this plan: Prepare standard solutions of known strength in moles per liter of sulfuric, nitric, and phosphoric acids, and potassium, calcium, and magnesium hydroxides. (See p. 60 in Turner's book.) Now you can prepare the deficiency solutions by leaving out in turn the various ingredients in the formulas shown in Turner's book. The last step will be to adjust the pH by adding more acid or base as needed. Supply the minor elements and iron by the usual methods unless your experiment is concerned with them. Otherwise, prepare the minor element solution without the ingredient you wish to leave out.

Organize your group so that the work of the experiment is divided, part of the class preparing the solutions, part of the class setting up the growth tests. You should run your growth tests in pairs, and also run growth tests with the complete mixture, for comparison. Thus you might have two pots each deficient in N, P, S, K, Ca, Mg, Fe, B, Zn, Cu, and Mn, and two with complete solution. In each pot would be sand in which would be growing two radish, two lettuce and two chard plants. This makes twenty-four pots and 144 plants. If the pots are small, put in fewer plants in each.

When the results are clear, study the appearance of the plants which are deficient in various chemical elements. You could drill yourselves by covering the labels on the pots and guessing which chemical is deficient. This kind of skill will aid you in diagnosing the symptoms of your plants.

B. CORRECTION
How to remove deficiencies of various elements

After spotting probable deficiencies, you will want to supply the missing chemical elements. Following are some hints on the best ways to go about this.

1. How to check or verify the presence of deficiencies. It might be possible to diagnose certain deficiencies by appearance only, such as iron deficiency. For some others, however, it is possible to make mistakes. For example, Hambidge, p. 62-3, tells us that symptoms of N deficiency of corn plants may actually be due to lack of P. Laurie, p. 45, says that deficiencies of P and K are hard to tell apart in carnations. The use of an "indicator" plant such as our radishes, may be an additional safeguard. Another positive method, short of complete tests of the solution, is the use of chemical tests of plant tissues. These have been developed for N, K, and P, and we shall learn about them in the next chapter. In any case, it is wise to check your observation of plant appearances by other methods before taking action, except in supplying iron.

2. How to replace deficient elements. When a deficiency of some element has been found, add the proper amounts to bring the concentration of that element back to normal. Use the compound which will supply other elements which are, or probably are deficient. N may be added as KNO_3 or $\text{Ca}(\text{NO}_3)_2$. In any case, keep careful records of amounts added. Careful observation will show relationships between light and temperature conditions and the use by plants of N, K, etc. Turner, on pp. 132-142, shows sample record forms to use.

3. How to supply the minor elements. The minor elements--iron, manganese, boron, copper and zinc, are minor in name and in quantity only. Complete absence of any one gives serious results. The illustrations on the following page show the contrast in the growth of melons on two farms, one supplied with a supply of all the minor elements (boron not added), and an adjoining field not given this treatment. However, slight excesses of these elements are toxic. The analysis of the water supply and of the main chemicals should be checked to determine the probability of deficiencies. Iron should be added regularly, once or twice a week, especially in hot bright weather, and the pH kept on the acid side to make iron, as well as other minor elements available. The other trace elements can be supplied once a month. In sand culture the minor element supply is not so critical. Amounts that would be excessive in water culture will not harm plants in sand culture, up to a certain point. See Chapter 2, Table I for one method of preparation of a solution of minor elements. See Chapter 7, B, 1, g for a detailed problem on preparation of a trace element solution.

ASSIGNMENTS

Projects in the diagnosis and correction
of plant deficiencies

1. EXPLORATORY PROJECTS: Assignments to help you gain skill in reading the condition of your plants.
 - a. Repeat, expand, or modify the experiments described in the chapter. Drill yourself on recognizing deficiencies.
 - b. In connection with a soilless garden project, grow radishes separately, supplying them with your nutrient solution diluted



A. Crops supplied with N, K, P, fertilizer, plus a product of city incinerator ashes supplying trace elements (except B)



B. Crops supplied with standard N, K, P, fertilizer only

FIGURE 4. EFFECTS OF SUPPLYING TRACE ELEMENTS
IN DEFICIENT SOIL (IMPERIAL VALLEY)
(Courtesy of Hemig's Soluble Minerals Co., Los Angeles)

to half strength, thus anticipating deficiencies before they become serious. Keep a record of the effectiveness of this method of checking your nutrient solution.

2. PRODUCTIVE OR PRACTICAL PROJECTS: Application of your acquired skills in diagnosing and correcting plant symptoms.

- a. Keep radishes starting at one-week intervals in the same solution as your tomatoes or other plants, and use them as indicators of solution conditions.
- b. Watch closely for symptoms of deficiencies in your soilless garden, and supply lacking elements after checking by tissue tests, solution tests, or other reliable check.

EVALUATION

Some methods of testing your skill in diagnosis
and correction of plant deficiencies

1. MOVING PICTURE CHECK: Use your moving pictures in a new way:

Re-show one or more of the moving pictures which you saw before, without the sound, and test your diagnostic skill by writing down what elements should be supplied to overcome various plant deficiencies.

2. DEFICIENCY EXPERIMENTS: Make the most of your work: Have the

teacher test you on your ability in diagnosis by showing you the plants of your class experiment, with the labels covered or removed, and identify the deficiencies.

SOURCES

Materials which should be of special help in the
identification and correction of deficiencies

1. MOTION PICTURES: Films showing deficiencies: See the List of
16 mm. Motion Picture Films, b,c,d, or e.
2. RESERVE SHELF BOOKS: See the following references: Bear, 231-289;
Connors, 16-21, 35-72, 145-167, 193-6; Ellis, 1-18, 213-26; Gericke,
10-14, 108-23, 236-7; Hambidge, i-iv, the whole book: especially,
117-8, 141, 176, 224, and 296; Laurie, 40-73, especially, 72-3,
101-13; Spessard, 38-48, 78-98; Turner, 35, 74-86, 104-14.

CHAPTER 7. SOLUTION CONTROL HOW TO ANALYZE AND ADJUST THE NUTRIENT SOLUTION

In Chapter 2 we learned how to provide in our solutions the chemicals that plants need in their growth. If we are going to maintain ideal conditions, we will need to replace chemicals as they are used up by the plants. In Chapter 6 we learned to watch for symptoms of deficiencies in the plants, as warning signs. In this chapter, we want to learn some more certain and direct methods of testing whether chemicals have been partly or almost wholly used up by plants. Then, of course, we will replace the used-up chemicals in the solutions, and adjust the pH or acidity to the right point. Along with these techniques we want to go a little deeper into the techniques and principles of preparing nutrient solutions.

A. PLANT TISSUE TESTS How to test for presence of chemicals in leaves and stems

One way to tell whether plants are getting a supply of N, K, P, etc., is to make chemical tests of leaves and stems. These tests are fairly simple and easy to make, even for amateurs. The advantage is that we rely on "qualitative" tests, instead of "quantitative" ones. In chemistry, qualitative tests are simpler and easier to make.

1. How to prepare samples for plant tissue tests. We suggest that you follow the instructions in Hambidge, pages 81-4, or Bear, pages 190-4, in performing these tests. Various methods are used for various plants and in testing for various elements. In some tests the stems are sliced and a few drops of test solution applied. Certain

colors indicate the presence of certain chemicals. In other tests the leaves are chopped or pounded or "homogenized" by the use of a machine, before testing.

2. How to prepare reagents and perform the tests. We will give a few general hints here only. Consult the above references, and others cited at the end of the chapter. Do not attempt to carry out these tests without a suitable place and equipments to do them. You need a sink and running water, paper towels, a supply of baking soda, etc. If this is your home laboratory and there are children around, you need to keep it locked for their protection from dangerous chemicals. If you have not had experience in chemistry, get the help of someone who can perform the chemical tests to show you how and caution you about the hazards. Special care must be taken with concentrated sulfuric acid, H_2SO_4 , which is very corrosive. Never add water to it, as it is likely to spatter, because of the sudden formation of heat. If you need to mix it with water, add it slowly to the water, stirring with a glass rod. The glass beaker or jar will get quite hot in this operation.

In case of accidental contact with sulfuric acid, wash the skin, and apply dry or dissolved baking soda, $NaHCO_3$. Soda will also neutralize acid spilled on furniture, the floor, etc. Drops on clothing will make holes, unless the acid is quickly neutralized. Wear a rubber apron for protection.

After your tests are finished, add to the solution in proper form and amounts, the elements found to be lacking in your plants. If you add $3/4$ of the original amounts of N, K, or P to your solution whenever plants show the need by tissue tests, you won't go wrong.

B. NUTRIENT SOLUTION CONTROL
How to maintain a more accurate composition
of nutrient solution

A football player who began playing football without learning the rules would be very foolish, wouldn't he? So we too, in playing with chemicals, had better take "time out" to learn something about how to play the "game of chemistry" with old "Mother Nature", so that we will not run 50 yards for a touchdown—in the wrong direction!

1. How to play the "game" of chemistry. Scientists have worked for hundreds of years to discover many chemical facts. They have finally discovered certain principles which explain these facts so that high school students can and do understand them after a few weeks or months of study. We are not going to launch into a course in chemistry, but only to learn enough to choose the most economical source of nutrient elements and to understand something of what is going on in our solutions. We think you can work better with chemicals and solutions if you understand the reason why some things that happen do happen.

a. Composition of matter. All matter, and in particular the chemicals we have been supplying to our plants, is composed of atoms of elements, of which there are 92 known. (More since recent developments in atomic research.) As we have said, the elements which plants need are the major elements, abbreviated N, K, P, Ca, Mg, and S; the minor elements, Fe, Mn, B, Zn, Cu (and Mo); and also, from air and water, H, O, and C. These elements combine with each other in definite amounts to form compounds of definite characteristics. For example, H, a gas,

and O, another gas, combine by burning in the ratio of 2 to 16 by weight, to form water, H_2O , a liquid at ordinary temperatures. By passing a direct electric current through water, we may get back our H and O again, as gases. Now, while H and O combine in the ratio 1 to 8 by weight, the ratio of the volumes of gas is 2 to 1. Other gases which combine in certain ratios are: H and Cl, 1 to 1; N and H, 1 to 3. It may strike you as strange that these neat small numbers describe so well the behavior of these gases. With these clues and many others, chemists have constructed interesting theories to account for the behavior of our invisible chemicals as they travel about in our solutions.

b. How to compute percentage composition of chemicals. The atoms of a particular element, for practical purposes, are all alike. An atom of H weighs $1/16$ what one of O weighs, and $1/12$ what an atom of C weighs, and so on. So it is convenient to choose numbers to represent the weights of the various elements. To make these come out as whole numbers, we set the weight of O at 16. (Not 16 pounds, ounces, or grams; just 16.) This makes many atomic weights come out nearly whole numbers. You can find them in any chemistry text-book. The atomic weights of interest to us are as follows, rounded to whole numbers:

B	11	Cu	64	Mg	24	P	31
Ca	40	H	1	Mn	55	K	39
C	12	I	127	N	14	S	32
Cl	36	Fe	56	O	16	Zn	65

Atoms of elements combine to form molecules of compounds. The formula H_2O means that 2 atoms of H are combined with 1 atom of O, forming

1 molecule of H_2O , or water. A molecule is a separately existing particle, and is the smallest amount of a compound, just as an atom is the smallest unit of an element. The formula H_2O also means, when we consult the atomic weights, that 2 H atoms, weighing 1, combine with 1 O atom, weighing 16. So the H to O ratio by weight in water is 2 to 16, or 1 to 8.

c. Sample problem on cost of a chemical element. Let us take the formula KNO_3 , potassium nitrate, a common and important hydroponic chemical. 39 parts by weight of K are combined with 14 parts by weight of N and $3 \times 16 = 48$ parts by weight of O in this chemical. So in 101 lbs. of KNO_3 there are 39, 14, and 48 lbs. respectively of K, N, and O. In 101 ounces of KNO_3 , there are ____, ____, and ____ ounces, respectively, of K, N, and O?

So, the chemical KNO_3 is 39 parts by weight K out of 101 parts total, or $39/101 \times 100 = 39(-)\%$ K. Likewise it is ____ parts by weight N out of ____ parts total, or $14(-)\%$ N. Check this figure.

Illustrative Problem 1. Which is cheaper as a source of K: potassium nitrate, KNO_3 at \$3.50 for 100 lbs., or potash, K_2O , at the same price? Considered as a source of K only, we are paying \$3.50 for 39(-) lbs. of K in KNO_3 (KNO_3 is 39% K, see above) or 9¢ per lb. What percent of K_2O is K? ____ How much per lb. is the K in K_2O ? _____. Check our figure of 4.1¢ per lb.

Since 100 lbs. of KNO_3 supplies ____ lbs. of N also, we must take this into account in buying chemicals. Generally it pays to buy combinations of our hydroponic elements, since we get two at the same time.

d. Advantages of using chemical formulas. Now to the chemist, the

atomic weights and the formulas are of great practical importance, because they enable him to solve problems like the one we just solved. Without atomic weights and formulas, and other chemical discoveries, each mineral like epsom salts, gypsum, bluestone, and so on, would be a new mystery, in a class by itself. We want to know enough about chemistry to help us to manage our solutions. The chemical names for these three are, respectively, magnesium sulfate, MgSO_4 , calcium sulfate, CaSO_4 , and copper sulfate, CuSO_4 . The mineral names epsom salts, gypsum, and bluestone tell us nothing about the composition, whereas the chemical names do tell us something. Each one is a sulfate; each formula contains SO_4 ; you can see that they are related. You would never know that they were related in this way by their appearance, nor by their common names. It takes a system of hundreds of carefully done chemical experiments to discover these facts, but these experiments are neatly abbreviated for us in the formulas CaSO_4 , MgSO_4 , and CuSO_4 . Using them, we can find the percentage composition by weight of Ca, Mg, or Cu in the three chemicals, or of the group SO_4 . You may find it useful to practice a little on that kind of problem for the sake of drill.

e. Illustrative problem on cost of magnesium. The mineral kieserite, costing \$20 a ton, has the formula $\text{MgSO}_4 \cdot \text{H}_2\text{O}$; the mineral epsom salts, costing \$40 a ton, has the formula $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$. Either one would supply Mg and S to our plants. Which one is cheaper? Well, you can see right away that epsom salts is twice as high to begin with, and has seven times as much (H_2O) in it, as kieserite, so kieserite is quite a lot cheaper. As a source of MgSO_4 only, how much does each one cost per ton?

$$\begin{aligned}
 \text{Cost of MgSO}_4 \text{ in kieserite} &= \frac{\text{cost of kieserite}}{\text{ratio of MgSO}_4 \text{ in MgSO}_4 \cdot \text{H}_2\text{O}} \\
 &= \frac{\$20 \text{ per ton}}{\frac{\text{weight of MgSO}_4}{\text{weight of MgSO}_4 \cdot \text{H}_2\text{O}}} = \frac{\$20 / \text{ton}}{24+32+4 \times 16+2+16} \times \frac{24+32+4 \times 16+2+16}{24+32+4 \times 16} \\
 &= \frac{\$20}{120} \times \frac{120+18}{120} = \$ \frac{138}{6} = \$23 \text{ per ton}
 \end{aligned}$$

$$\begin{aligned}
 \text{Similarly, cost of MgSO}_4 \text{ in epsom salts} &= \frac{\text{cost of epsom salt}}{\text{ratio of MgSO}_4 \text{ in MgSO}_4 \cdot 7\text{H}_2\text{O}} \\
 &= \frac{\$ (\quad) \text{ per ton}}{\frac{\text{weight of MgSO}_4}{\text{weight of MgSO}_4 \cdot 7\text{H}_2\text{O}}} = \frac{\$ (\quad) \text{ per ton}}{\frac{(\quad) + (\quad) + 4 \times (\quad)}{(\quad) + (\quad) + 4 \times (\quad) + 7 \times (\quad) + (\quad)}} = \$82 \text{ per ton.}
 \end{aligned}$$

Check these results. You can see, therefore, that if you were buying very large quantities, it would pay to take much trouble to get the kieserite in preference to the epsom salts.

f. Sample problem on supplying copper. Another problem showing the importance of atomic weights and the method of supplying a necessary trace element is the following: What weight of copper sulfate, CuSO_4 anhydrous, should be added to 10 gallons of water to make .1 parts per million (p. p. m.) of copper, Cu, in the solution? We want .1 one-millionth of the weight of 10 gallons of water to be the Cu part of our CuSO_4 . A gallon of water weighs 8.33 lbs., which we can call 8 lbs., since in hydroponics we do not have to be as accurate as real chemists are. (So, "A pint's a pound, the world around." as the saying runs.)

Our 10 gallons of water will weigh about 80 lbs., and one-tenth of one p.p.m. of 80 lbs. is $.1 \times .000001 \times 80 = .000008$ lbs. Changing this to ounces, we multiply by 16, giving .000128 oz. of Cu that we want.

Now CuSO_4 is not all Cu, so what proportion of it is Cu?

$$\frac{\text{Cu}}{\text{CuSO}_4} = \frac{(\quad)}{(\quad) + 4x(\quad)} = \frac{2}{5} \quad . \quad (\text{Check these figures.}) \quad \text{To get 2 parts}$$
 of Cu it will require 5 parts of CuSO_4 , so to get .000128 oz. of Cu will require $\frac{5}{2} \times .000128 = \frac{5}{2} \times \frac{.000064}{2} = .00032$ oz. of CuSO_4 required.

How can we get 32 one hundred thousandths of an ounce of something? Here's an easy way: Dissolve, say, one ounce of CuSO_4 in a quart of water and stir it up. Now it is all distributed evenly. If we take a small part, say a tablespoon, we get a small part of the 1 ounce of CuSO_4 . Since there are 16 tablespoons in a cup, and 4 cups in a quart, we would have $\frac{1}{4 \times 16} = \frac{1}{64}$ of an ounce of CuSO_4 , in the tablespoon, or $\frac{2}{5} \times \frac{1}{64} = \frac{1}{160}$ oz. = .0063 oz. of Cu.

Comparing .0063 oz. of Cu in a tablespoon with .00032 oz., we see we have, if we fudge a little, $\frac{.00640}{.00032} = 20$ times too strong a solution. So, if we weaken our solution by mixing $\frac{1}{2}$ cup from our quart with 19 half-cups (= $10\frac{1}{2}$ cups = 1 qt., 1 pt., and $\frac{1}{2}$ cup) of water, the same Cu will be spread out through 20 times as much liquid as before, and one tablespoon will give .00032 oz. of Cu which we wanted to add to the 10 gallons of solution to get our .1 p. p. m. which is required. We suggest you go over this problem and do it over by yourself, so that you can carry it through.

g. Sample problem of providing a trace element solution. John Jones want to prepare a complete trace element solution, not including iron, which he plans to provide separately. He reads in the Encyclopedia Americana article on "Hydroponics" that the allowable range for

trace elements is:

Manganese (Mn)	1/2 to 4 p. p. m.
Boron (B)	1/5 to 1/2 p. p. m.
Zinc (Zn)	1/20 to 1/5 p. p. m.
Copper (Cu)	1/50 to 1/5 p. p. m.
Molybdenum (Mo)	1/100 p. p. m.

He believes that the water contains traces of boron, and that the galvanized water pipe will add small amount of zinc to the water. Therefore, he plans to provide the following p. p. m. of trace elements in the solution: Mn, 1; B, .1; Zn, .05; Cu, .1; and Mo, .01. He will prepare 10 gallons of solution at one time, which he expects to last a month, and then he will prepare fresh solution. He wants to prepare a trace solution of which he will add $\frac{1}{4}$ cup to the 10 gallons of solution. He has a letter scale which weighs 1 oz. conveniently, so he plans to dissolve 1 oz. of each of his chemicals in the correct amount of water so that he can then put $\frac{1}{4}$ cup of each into a quart jar and by filling the quart with water, have the correct solution to add $\frac{1}{4}$ cup to his 10 gallon tank.

He has the following chemicals: manganese sulfate, MnSO_4 ; boric acid, H_3BO_3 ; zinc sulfate, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$; copper sulfate (hydrated), $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$; and potassium molybdate, K_2MoO_4 . What amounts of water shall he use to dissolve each of his chemicals separately?

He arranges his work in the form of a table, as follows:

Elem. X	Comp. XYZ	Req. ppm. final.	Ppm after 2d dilut. (X640)	PPm after 1st sol. (X32)	Ppm of XYZ after 1st sol. $(X \frac{X+Y+Z}{X})$	Ant. water req., oz. $\frac{10^6}{10^6 - (\text{last fig.})}$
Mn	MnSO ₄	1	640	32x640	$.x55+32+64$ 55	56,600 16.7 oz.
B	H ₃ BO ₃	.1	64	64x32	$.x3+11+48$ 11	11,500 86 oz.
Zn	ZnSO ₄ ·7H ₂ O	.05	32	32x32	$.x65+32+64+126$ 65	4,520 227 oz.
Cu	CuSO ₄ ·5H ₂ O	.1	64	64x32	$.x64+32+64+90$ 64	8,000 124 oz.
Mo	K ₂ MoO ₄	.01	6.4	6.4x32	$.x78+96+64$ 96	508 1970 oz.

Continuation:

Elem. X	Water, Oz.	Water, Pints	Water, gals., qts., pts., cups.
Mn	$16.7 \times \frac{1 \text{ pint}}{16.7 \text{ oz.}} = 1$	1	1 pt.
B	$86 \times \frac{1 \text{ pint}}{16.7 \text{ oz.}} = 5.16$	5.16	1 qt. 1 pt. 1/3 cup
Zn	$227 \times \frac{1 \text{ pint}}{16.7 \text{ oz.}} = 13.63$	13.63	1 gal. 1 qt. 1 pt. 1 1/3 cups
Cu	$124 \times \frac{1 \text{ pint}}{16.7 \text{ oz.}} = 7.5$	7.5	1 qt. 3 pts. 1 cup
Mo	$1970 \times \frac{1 \text{ pint}}{16.7 \text{ oz.}} = 118.2$	118.2	14 gal 1 qt. 2 pts. 1/2 cup.

2. How to vary the composition of your solutions. Scientists have done considerable work in the search for the best combination of chemicals for many plants. As a result, they have concluded that the best one is not much better than an average combination.. Plants will grow well with any one of a large number of combinations. However,

the chemicals used up must be replenished before plants suffer from lack of them. Thus the Encyclopedia Americana article on "Hydroponics" gives the following minimum and maximum quantities, in parts per million, for the various elements:

Nitrogen (N)	90 to 350 p. p. m.
Potassium (K)	90 to 450 p. p. m.
Calcium (Ca)	150 to 570 p. p. m.
Sulfur (S)	100 to 560 p. p. m.
Phosphorus (P)	30 to 150 p. p. m.
Magnesium (Mg)	10 to 110 p. p. m.
Iron (Fe)	1/2 to 4 p. p. m.
Manganese (Mn)	1/5 to 2 p. p. m.
Boron (B)	1/5 to 1/2 p. p. m.
Zinc (Zn)	1/20 to 1/5 p. p. m.
Copper (Cu)	1/50 to 1/5 p. p. m.
Molybdenum (Mo)	1/100 p. p. m.

Plants have been grown successfully within the stated extremes of each of these chemical elements. However, we could not use the maximum quantities for all the elements, since this would make the solution too concentrated. The total parts per million of the solution may vary from a minimum of 500 (Gericke) to 3000, or even more for special purposes for short periods. A good figure is 1000 to 1500 p. p. m. of chemicals in the solution.

An important consideration is the amount of chemicals already present in the faucet water to which you are adding your chemicals. You should obtain an analysis of these chemicals and make allowance

for calcium and magnesium compounds in this water, subtracting these amounts from your formula. Consult the chapter in Gericke on this subject.

3. How to measure solution deficiencies directly. We do not propose to give detailed instructions on the chemical testing of solutions. This subject is well covered in several of the Reserve Shelf Books. The pages are listed at the end of this chapter. In any case, you should learn these techniques in a laboratory under the instruction of an experienced person. If you have studied chemistry and have laboratory facilities, you can work out the testing techniques with the aid of the references cited. The tests in general depend on comparison of color or turbidity of the sample with a standard. A standard is better to use than a color chart. Set aside some of the original prepared nutrient solution, against which to run the samples later after the plants have depleted the chemicals in the solution. Prepare several dilutions of the original nutrient solution, and determine which one of these is matched best by your sample. Accuracy, dexterity, cleanliness, and ingenuity are important in this kind of work. In a home laboratory it is important to protect the equipment from interference, and children from injury by locking the laboratory securely.

4. How to replace chemicals consumed by plants. After making the determinations of the amount of various chemicals that have been used up, you will be ready to replace them by additions of fresh chemical supplies. In Gericke's system, the formula is previously mixed to supply the plants' average needs, and additions of the total mixture are added whenever the nitrogen or phosphorus show depletion. About

once a month, the solution is discarded, to prevent accumulation of some unused elements in the formula, or perhaps in the tap water. In a large system, it is somewhat more economical to test all the various nutrients and make additions individually. Thus if the tap water does not contain appreciable amounts of sodium, chlorine, etc., the solution need not be changed for six months or so.

The labor of testing and replacing chemicals will be reduced if the elements being used rapidly by plants are kept at a high level. Thus Connors and Tiedjens report that nitrogen is used rapidly in summer months, while potassium is used slowly; in winter, this situation is reversed. Hence they raise the N level and lower the K level in summer, and raise the K level and lower the N level in winter. This makes it possible to test and replace nutrients less frequently.

The elements N, S, and Mg tend to be used up together in producing new growth of tissues; the elements Ca, P and K are used up somewhat independently of the first three.

We suggest you consult Spessard's book for the method of calculation of supply of nutrients used there, which applies to making up fresh solution and replacing used up elements as well. The methods of calculation used in section B, 1, g in this chapter, apply also to the major elements, except that salts supply two major elements at the same time. Thus you may add N and K in KNO_3 , or N and Ca in $\text{Ca}(\text{NO}_3)_2$. It is also possible, in the case of N only, to supply the element alone, in the compound ammonium nitrate, NH_4NO_3 . This can be used only in summer conditions, however, and with caution. Keep exact records of chemicals

added to your solutions. It seems that in the non-metals, sulfur, and in the metals, potassium and calcium can be varied considerably without harmful effects. Thus the needed elements can be paired with one of these if another needed element cannot be paired with it.

* * *

ASSIGNMENTS

Projects in testing and adjusting solutions

1. EXPLORATORY PROJECTS: Assignments to help you gain skill in performing tests and calculations.

- a. Plant tissue tests. Learn to perform the plant tissue tests described in Hambidge, p. 81-84, well enough that your results agree with those of experienced users of these tests.
- b. Solution tests. Learn to perform one of the series of solution tests cited at the end of the chapter so that you can determine the amounts of nitrate, phosphate, potassium, calcium, and magnesium in an unknown (to you) solution furnished by the instructor with reasonable accuracy.
- c. Learn to cut down chemical testing of the solution to a minimum by making calculations of nutrients used up based on the growth of your plants and their known chemical composition. See Gericke, p. 57, two paragraphs starting at the foot of the page.
- d. It is unreasonable to dissolve 1 oz. of potassium molybdate in over 14 gal. of water, as indicated by the answer to the problem in B. 1, g. What would you suggest doing? Draft a detailed

description to avoid this unwieldy procedure.

2. PRODUCTIVE PROJECTS: Cashing in on skill learned by drill.

a, b, and c. After attaining proficiency, use plant tissue tests, solution tests, and calculations like those in "c" above, to guide you in supplying plant food to a large scale productive unit.

EVALUATION

**Suggestions for checking your progress
in managing solutions**

- 1. AGREEMENT: Compare your results with those of others:** Ask the instructor to check your results in performing plant tissue tests by the results of others with the same samples. Have him check your analytical results against the known composition of the "unknown" samples. Compare your calculations in "c" above with those of others to spot errors in computation, errors in data, or errors in assumed principles of plant nutrition.
- 2. ADVICE: Seek constructive criticism:** Ask experienced analysts to give you tips on improving your techniques.
- 3. RESEARCH: Improve through further study:** Continue to look for short-cuts and more accurate tests through reading, observation and practice.
- 4. PAPER AND PENCIL TESTS: Answer and be checked on questions like the following:** Place an X in the proper parentheses:
 - a. (X) () In solution analysis, it is better to run standards for comparison than to rely on color charts.
 - b. () (X) In plant tissue tests it makes little difference where the sample is cut from.

- c. (X) () Lack of nitrogen or phosphorus alike may result in excess sugar in the tissues.
- d. (X) () In phosphorus deficiency, plants cannot use the nitrogen they contain.

SOURCES

1. MOTION PICTURES: Films giving help on this chapter:

Film "d" in the "16 mm. Motion Picture Films."

2. RESERVE SHELF BOOKS: See the following references: Bear, 137-55,

190-4; Connors, 72-8, 180-93, 196-216; Ellis, 155-73, 237-265;

Gericke, 9-10, 51-2; Hambidge, 137-55 (?), 81-4, 222-3; Spessard,

111-21; Turner, 62-73, 87-104.

CHAPTER 8. COMMERCIAL OPERATION HOW TO UNDERTAKE LARGE-SCALE CHEMICULTURE FOR PROFIT

If you are interested in profitable work in soilless gardening, you may belong to one of three kinds of people. You may be a present or future greenhouse operator interested in adopting the most economical operating procedures. Or you may be interested in truck farming and willing to experiment with novel but practical methods of producing superior vegetables. Thirdly, you may be interested in specializing in this method of production in order to produce crops in situations where soil methods would fail or be difficult to carry on. This is the case in tropical countries where soil pests, ants and other insects and birds are so destructive that scientific techniques for getting maximum yields are a good investment.

Also, you are probably a student, and if you plan to earn cash through soilless gardening, that is still in the future. With these possibilities in mind, this chapter is written to give you some advice on converting an interesting hobby into a profitable business venture.

A. GREENHOUSE PRODUCTION How to reduce costs in greenhouse operation

In conventional greenhouse operation, plants are started in flats from seed or from slips in moist sand and transferred to pots, gallon cans and five gallon cans as they develop. Different species of plants require different types of soil as to drainage, coarseness, acidity, etc. Supplies of good rich soil must be obtained, which are mixed with sand and fertilizer for potting.

According to Laurie, a field should be planted to several cover crops which are plowed under before it is ready to use for greenhouse soil. Then after a period of use, the soil needs to be heated by steam to kill harmful one-celled animal life which preys on beneficial bacteria and thus destroys soil fertility. You can readily see that this requires special equipment and considerable labor.

Because of these facts, and others, it is calculated that a greenhouse can be operated with a saving of 15% to 25% in costs if equipped with pumps, waterproof beds, pipes, and tanks for carrying on sand or gravel culture of plants. A greenhouse operator who wishes to adopt chemical culture methods should change over piecemeal, so as to gain experience on a small scale before putting all his eggs in this kind of basket.

Because this is a big subject and of much importance to anyone undertaking this work, we cannot hope to cover it adequately here. The following outline is offered as an aid to studying these problems. The interested person should study the materials cited at the end of the chapter, as well as other materials available on this subject.

1. How to adapt a greenhouse to nutrient culture (sub-irrigation of sand or gravel).
 - a. How to reconstruct old benches.
 - (1) Flat bottom benches should be rebuilt, or tipped for a slight cross slope. (Or see Spessard's diagrams and instructions.)
 - (2) Cover knot-holes with pieces of sheet metal.
 - (3) Waterproof with standard roofing materials and methods.

- (4) Brace and strengthen framework.
- (5) Study the cited references.
- b. How to build new growing beds.
 - (1) Choose types for economy, ease of installation, or convenient labor, as you prefer. (See especially Ellis.)
 - (2) Get a professional experienced builder to construct them.
 - (3) Prevent standing water by correct sloping.
 - (4) See the references, especially Ellis.
- c. How to install pumps, piping, and tanks.
 - (1) Provide tank capacity from half to equal that of beds.
 - (2) Coat tanks with asphalt paint, emulsion, or hot mop.
 - (3) Provide for flooding and draining in 10 minutes.
 - (4) See the references.
- 2. How to acquire experience while converting to soilless culture.
 - a. Install a large number of bucket-and-box units.
 - b. Provide varying formulas, varying coarseness of sand, varying flooding cycles between units.
 - c. Adopt the best procedures found for the larger sub-irrigation units.
 - d. Read the literature cited.

B. TRUCK CROP PRODUCTION

How to raise superior vegetables for profit

One reason for producing vegetables by soilless methods is that they can be grown under controlled nutritional conditions, and when

properly grown they will be more nutritious and better tasting than soil-grown vegetables. Properly developed, there should be a unique market for these products. Following are some suggestions in outline form for working up a business based on these possibilities.

1. How to gain experience and skill in producing soilless garden vegetables.
 - a. Follow the methods indicated above for gaining experience in greenhouse crops.
 - b. With limited capital and experience, study the Spessard and Gericke methods of crop production. (See their books)
 - c. If you can operate one or a few units successfully, you can operate more with little additional labor.
 - d. After operating by these methods for a time, you could expand production by installing pumps, beds, etc. for more automatic operation.
 - e. Study your operations to find labor- and time-saving improvements.
2. How to develop a market for your products.
 - a. Market in a locality where people appreciate vegetables of superior taste and nutritive value.
 - b. Package your goods distinctively and attractively.
 - c. Choose a brand name and meaningful slogan conveying the healthful quality of your vegetables.
 - d. Substitute the word "mineral" for "chemical" in describing products.

(Note: There is a widespread prejudice against "artificial" methods of

stimulating plant growth. This has some foundation in the harmful results of using incomplete commercial fertilizers in soil, which permits plants to grow and further deplete soils of elements not supplied in these fertilizers. Eventually, all soils will become exhausted unless all essential elements removed by plants are returned.)

- e. Anticipate and overcome prejudice by explaining the origin of false notions.
 - f. See that your products are marketed rapidly, under refrigeration if possible.
 - g. Include a brief circular in your package, telling the nutritional merits of your product, possibly give recipes.
3. How to maintain economical production.
- a. Expand your business to the point where your operations are efficient.
 - b. Train part-time high school or college help to do the chemical testing.
 - c. Buy chemicals in 100 lb. lots or more.
 - d. Master the principles of formulas so as to shop for the most economical adequate combination.
 - e. Experiment with cheap materials. (Wood and other plant ashes, combined with nitric and sulfuric acids, etc.)
 - f. Cut maintenance and repair costs by constructing with durable materials.
4. How to obtain high productivity.
- a. Study the factors of high productivity in soil crops.
 - b. Give thought to root-top temperature relations.

- c. Check and improve aeration conditions of roots.
 - d. Study light, day-length, and temperature curve factors in fruiting.
 - e. Reduce supply of nutrients at maturity of plants to induce fruiting.
 - f. Keep alert: study your business.
5. How to minimize risks:
- a. Price collapse: study market trends for best timing of your crops.
 - b. Market glut: put your product in a class by itself by methods suggested in "2" above.
 - c. Unavailable chemicals: stockpile "bottle-neck" chemicals and be familiar with alternate formulas.
 - d. Insect pests: be alert to the first signs, spray, dust; get help of the Bureau of Entomology.
 - e. Plant diseases: choose resistant varieties; do not harbor insect carriers.
 - f. General: anticipate adverse conditions; do the proper amount of worrying.

C. LARGE INSTALLATIONS

How to set up and operate projects supplying
corporation personnel, army units

It is in this field that chemical gardening has reached the greatest proportions, dwarfing all other forms of operation. Only a few hints can be offered here to those interested in this spectacular and rapidly developing field. The best book is perhaps that of Ellis and

Swaney, but the Army Technical Training Manual, "Nutriculture", listed in the bibliography, should also be excellent.

A person desiring to get into this kind of work would perhaps do well to apply to the army requesting the opportunity to work in Japan, where extensive installations are in operation. No doubt opportunities also exist for interested persons with corporations operating installations in the tropics and other places.

An idea of some of the special problems encountered in the tropics may be gained from the chapter "Common Detriments" in Ellis. Some other special problems would be the organizing and training of workers, the planning and construction of installations of the right capacity to supply a given number of consumers, the obtaining of large amounts of chemicals of the required purity, and other problems. In some installations, even the water must be obtained by distillation from sea-water.

The successful operation of these huge installations producing tons of vegetables stirs the imagination of anyone concerned with problems of food supplies for the world's increasing population. Efficient though they are, they do not approach the limits of possible efficiency, since most of them use up considerable areas in pathways, and also dissipate considerable amounts of light by partial shading with netting.

Because these installations have had to be rapidly built and put into operation, have had to rely on tested methods, have transported chemicals long distances, have been operated as necessities without regard to cost, and for other reasons, they may still be far from peak efficiency and maximum economy. Only the future will reveal what is

ultimately possible. Undoubtedly this would be a fascinating and promising field of work for anyone to enter.

ASSIGNMENTS

Projects in soilless gardening for profit

1. EXPLORATORY PROJECTS: Procedures to help you "feel your way" into profitable soilless gardening.

- a. Draw up plans for a hydroponicum of commercial proportions, estimating investment, cost of operation, maintenance, operation and labor, and probable income.
- b. Set up a small-scale "pilot plant" hydroponicum and operate it for a season, keeping careful records of costs, yield, labor, etc. Using these records, work out plans for the operation of a full-scale commercial hydroponics enterprise. Include means of combatting insect pests, plans for operation during your vacation or in case of your illness. Be able to meet possible shortages of certain chemicals by stockpiling or by use of alternate formulas.

2. PRODUCTIVE PROJECTS: Serious, full-scale undertakings in profitable soilless gardening.

- a. Launch into a commercial hydroponics venture, first having tested its soundness by procedures such as "a" and "b" above.
- b. Get employment in a greenhouse using soilless gardening methods.

EVALUATION

Some means of checking your soilless
gardening business ability

1. ADVICE: Take advantage of the help others can give you: Have your prospectus, (Project 1, a) for a commercial venture examined and criticized from a financial and from a technological standpoint. Get similar criticism on Project 1, b.
2. PAPER AND PENCIL: Answer and be checked on tests like the following:
Place an X in the proper parentheses before each question:
 - a. (X) () You can save 15% to 25% in greenhouse operating costs through soilless methods.
 - b. (X) () You should operate units on a moderate scale, keeping careful records, before launching a commercial project.
 - c. (X) () If you have a high degree of skill and limited funds to invest, you should undertake water culture.
 - d. (X) () To operate a commercial enterprise on the largest scale, you should go into gravel culture.
3. RESULTS: Gauge your success by the outcome of your venture: The final test will be the income you make and the service you render in producing desirable, good quality products.

SOURCES

Materials to aid you in commercial projects

1. READING: Consult references like the following:
 - a. Reserve Shelf Books: Ellis, 55-60, 174-212; Gericke, 229-35, 257-70; Laurie, 114-68; Spessard, (see index); Turner, 8-29, 121-5.
 - b. Encyclopedia Americana, article "Hydroponics".
2. COMMERCIAL DATA: Use price quotations, circulars, lists: Catalogs of chemical supply houses, nursery supply houses, etc.

3. GOVERNMENT SERVICE: Market price information: Get the Daily Produce Wholesale Market Reports from the U. S. Dept. of Agriculture Marketing Service. Sent free on request.
4. MAGAZINE ARTICLES: Consult business magazines: Read articles in Business Week, Fortune, etc., which discuss soilless gardening.
(See Magazine References 5, 8, 31.)

CHAPTER 9. QUALITY IMPROVEMENT

HOW TO PRODUCE EXCEPTIONAL QUALITY IN VEGETABLES

In taking up this phase of soilless gardening we are venturing into a field which has not been developed to any great extent. It has been established that hydroponically grown foods are richer in mineral content than soil-grown foods. It is also established that you can increase the calcium, nitrogen, phosphorus, or other content of crops by feeding the plant roots a solution high in the element you wish to increase, during the last half or third of their growth. Let us take up these two aspects of the mineral content of foods, the all-round balance, and special emphasis on particular ingredients, and learn what we can about obtaining high mineral quality.

A. BALANCED HIGH MINERAL CONTENT

How to get all-around high mineral quality

Hydroponics gives us a greater degree of control of plant nutrition than is possible in soil, because soils tend to "lock up" certain fertilizer elements: phosphates are made insoluble by calcium in the soil, iron, manganese and boron in alkaline soils are unavailable to plants, copper is "locked up" by black peaty soils, and so on. Farmers try to maintain their soils at neutrality or on the alkaline side, because acid soils tend to make too much aluminum available to plants for their health. In hydroponics, since we do not add aluminum, we are able to give plants a slightly acid medium so that iron and the minor elements are available. A good chemistry text will explain these matters under the topic of "solubility products". For our purposes, it is enough to

know that there are certain advantages peculiar to soilless gardening, as well as certain problems associated with it.

1. How to get high mineral content compared to soil grown products.

Gericke gives the following facts about the mineral content of soil-grown compared to hydroponically grown tomatoes, (p. 242):

	Potash %	Phosphate %	Magnesia%	Sulfate%	Lime %
Soil	.99	.21	.05	.06	.20
Hydro.	1.63	.33	.10	.11	.28

Although it would be possible to produce these results in soil, it would take higher amounts of chemicals, since part of the chemicals are "locked up", as explained before.

So, by following the methods we have already been practicing, and replacing the chemicals as they are used up by the plants, we achieve these desired results.

It may be possible, that by selecting particular species of plants, we could produce leaf vegetables with especially high mineral content. Perhaps New Zealand spinach or some succulent-type edible plants would be suitable. Seashore plants contain large amounts of minerals, as well as various desert plants, some as high as 20% or more.

2. How to include elements desirable in human food but not needed by plants. Sodium, chlorine, iodine, and perhaps some other elements are needed for human nutrition, but not for plants. On the other hand, plants sometimes contain, although they do not need, elements which are harmful, or even poisonous to humans or to animals. The outstanding case is "Suicide Gulch" in Colorado where plants contain sufficient selenium to kill large numbers of sheep which have eaten them.

Standard practice in hydroponics has been to supply elements needed by plants only. Perhaps vegetables would be more tasty, and certainly more nutritious, if iodine, sodium, and chlorine were added to the nutrient solutions.

B. EMPHASIS ON SELECTED ELEMENTS
How to increase proportions of particular elements

As previously stated, this subject is still in the exploratory stage. More needs to be known about which mineral elements are lacking in diets, and the best methods of supplying them. Here are presented in outline form some of the problems involved in these processes and some suggestions for their solution.

1. How to meet a real need for deficient elements.

- a. Study the diet requirements of people. (Take courses or read books on nutrition.)
- b. Study the food habits of people, and ways of improving them. (Study reports of surveys.)
- c. Get information on groups of people with allergies or diet peculiarities, in order to supply their needs. (People allergic to milk might eat specially grown calcium rich vegetables. Those unable to assimilate iron in pill form might be able to get it in vegetables, fruit, berries or grapes.)
- d. Keep up with scientific research and discoveries on this subject, and take advantage of it in your work.

2. How to increase vegetable or fruit content of desired elements.

- a. Do not attempt it with too fast growing, nor too slow growing plants. (See Gericks, p. 171-2.)
- b. Use leaf vegetables: parsley, spinach, and chard, etc.
- c. Give them a balanced solution for about half of their growth, then replace the solution with a compound of the element you wish to emphasize.
- d. Choose plants whose edible parts naturally contain a high proportion of the desired element.
- e. Special breeding or search might discover varieties of plants able to absorb more of various desired elements.

* * *

ASSIGNMENTS

Projects aimed at production of foods of
exceptional nutritive value

1. EXPLORATORY PROJECTS: Activities you may carry on as an aid to
learning the art of growing especially nutritive plant products.

- a. Obtain information on optimum nutritional requirements for various mineral elements, and on probable deficiencies in people's diets, by reading articles in encyclopedias, nutrition textbooks, magazine articles, etc. Have the vegetables you raise chemically analyzed and compare their content with soil-grown vegetables.
- b. Grow several vegetables and strawberries, etc., in a number of bucket-and-box units, subjecting them to procedures for emphasizing calcium and iron content, and other minerals found to be of value and lacking in diets.

- c. Search for and read reports of scientific experiments on the vitamin content of soil-grown compared to hydroponically grown vegetables or berries. Study research on producing maximum vitamin content.

2. PRODUCTIVE PROJECTS: Activities you may undertake to meet real nutritional needs of people.

- a. Produce vegetables or berries which are especially nutritious due to high amounts of needed minerals or vitamins, and sell them to people to whom these foods are recommended by doctors. Or sell your special products through health food stores to diet-conscious people.
- b. Produce all around high mineral quality vegetables to sell through regular food stores, including descriptions of their food value on circulars or leaflets in the packages.

EVALUATION

Some means of checking your progress
in meeting nutritional needs

- 1. ADVICE: Get help from others:** Talk with dieticians, physicians, health food merchandisers, and plant scientists about your tentative plans regarding this field.
- 2. LABORATORY ANALYSES: Test the quality of your products:** Obtain chemical or other tests of your food products to verify their exceptional nutritive value.

SOURCES

Materials which give help on this subject

- 1. RESERVE SHELF: Only one author treats this subject:** Gericke, 238-47.

2. OTHER AIDS: Look for materials on these subjects:

- a. Human nutrition requirements. See encyclopedia articles, texts on nutrition, and reports of scientific experiments and findings.
- b. Plant growth and mineral content. Reports of scientific experiments in this field, ash analysis, effects of special attempts to increase mineral content.
- c. Dietary deficiencies. Studies of average diets, prevalence of diseases due to, or partly due to mineral deficiencies.

CHAPTER 10. PIONEERING HOW TO CONTRIBUTE TO THE PROGRESS OF SOILLESS GARDENING

Soilless gardening is a growing field, in which much is left to be discovered, and much that has been discovered by scientists remains to be applied in a practical manner. Opinions about the practical possibilities of hydroponics are very diverse. In the first flush of enthusiasm around 1936 to 1940, many people experimented with it, and many wild notions and claims appeared. Persons qualified by knowledge and experience point to its limitations as well as its possibilities.

After some degree of success in soilless growth of plants, you may want to pursue this technique further. You may be interested for various reasons, such as (a) enjoyment of a fascinating hobby, (b) desire to discover important scientific principles, (c) desire to develop the money-making possibilities of soilless gardening, (d) the need to grow the most vegetables in your small area, (e) desire to produce better food from a health and taste standpoint, or other reasons. Roughly, we might classify these interests into two categories according to the amount of time you plan to give them. So we will offer some tips and suggestions to aid (1) those who intend to pursue soilless gardening as a part-time, spare-time activity, and (2) those who expect to enter into this field as a serious, money-making or professional activity.

A. SPARE-TIME SOILLESS GARDENING

How to develop new ideas in pursuing hydroponics at home

Following are some suggestions for ways of developing new angles in hydroponics as a spare-time activity.

1. How to work out new angles in hobbying. Many new ideas are waiting to be tried in home hydroponics for fun. A little time to putter, and a little imagination will bring them out. You may like to try out new plants, work out new artistic displays, or new and more convenient arrangements of solutions, and so on.

In this connection we may discuss the use of plant hormones or auxins, substances which affect the growth and development of plants. Many hard-to-root cuttings can be induced to root by applying weak solutions of these chemicals. They may be bought by asking for "rooting chemicals" at nurseries or seed stores. Some other "hormones" are sprayed on blossoms and fruit to prevent dropping, and to produce seedless tomatoes.

Several species of orchids are now grown with nutrient solutions, diluted to about one-tenth the usual strength. (See the Encyclopedia Americana article, "Hydroponics".)

In hobbying, or in home production, it may be to your advantage to form or join a soilless gardening club. Club members could benefit in several ways: they could buy chemicals cooperatively in economical quantities; they could set up a cooperative chemical laboratory; they can exchange information and ideas and compare results of methods; they can request formation of classes in public evening schools, and so on.

2. How to pave the way to more efficient home vegetable production. There is a great field for possible development of home production ideas in soilless gardening. There are perhaps millions of people who have insufficient space, or poor soil, or are unable to spade, rake and hoe, who would like to grow their own vegetables. At present there are many

problems or hindrances to overcome in hydroponics such as; (a) some equipment is elaborate, expensive, or of odd appearance. (b) Information about home production by soilless methods is hard to get and hard for laymen to understand. (c) Chemicals are hard to obtain in moderate quantities at reasonable prices in easily usable form. (d) Laboratory chemicals and equipment for analyzing solutions are expensive, or hazardous to handle or have in the home. (e) Testing and managing solutions is as much work in a small unit as in a large commercial one.

There are perhaps two avenues of approach in attempting to overcome these difficulties. One would be through the cooperative efforts of a club or class group working together and sharing their experiences, and another would be through research by some enterprising organization willing to supply the needs for a fair profit.

Some services which might be rendered by a commercial firm would be to supply tanks and chemicals on a monthly rental or service charge basis, or some other arrangement. One possibility which would relieve home operators of the necessity of managing the chemical solutions would be to supply these from a central source through pipes to each individual's tank, on a rental basis, letting him grow whatever he wished in his tank. Such schemes would entail many problems, but may be developed under special conditions sometime in the future. With the growth of cities and increase in population, these problems are likely to receive more earnest efforts at solution.

Experiments would need to be done and records kept on cost data and time required by home-owners to "grow their own". Advice on what to grow and what to avoid, based on careful studies, is needed. Salad

vegetables, lettuce, cucumbers, tomatoes, green beans, etc., seem to be the best possibilities, but other plants might also be practical.

3. How to pool and share ideas and experiences. The practical difficulties and problems we have discussed might be fruitfully attacked by the combined efforts of a group like a hydroponics club or class. Something like the following procedure might be followed: Let each club or class member write on 3x5 cards the problems or difficulties that prevent him from producing vegetables at home as efficiently as he would like, such as, high cost of chemicals, high price of tanks, cumbersome or unsightly appearance of tanks, etc. The cards can be arranged in a logical order, and placed in a file of "Unsolved Problems". Next, have class or group members write suggested solutions for these difficulties on 3x5 slips of, say, yellow paper. After discussing the solutions offered, pick out one or two best ideas and delegate someone to test them out in practice. When this has been done, the results can be reported on, say, a blue slip of paper, and inserted with the corresponding card and yellow slip in the file. As your group accumulates a collection of tested techniques for solving problems, build up a file of these, labeled: "Successful Methods in Soilless Gardening". Eventually you may collect enough of these to be able to prepare and publish a handbook or guide for people interested in carrying on home production.

Some suitable project for group research and experimentation would be: (a) What kind of a unit for home production is most practical for a family of four or five, considering investment, upkeep, trouble-free operation, time and labor required, and value of food produced? (b) What cultural conditions such as pH of solution, shading, chemical

formula, etc., produce the best tasting tomatoew, lettuce, etc.? (c)

Which common vegetables are profitable to grow, and which are not?

B. SERIOUS PURSUIT OF CHEMICAL GARDENING
How to contribute to the development of commercial
or scientific soilless gardening

Two kinds of people might be interested in intensive study of soilless gardening: scientific workers, and commercial producers. Here are some suggestions which may be of value.

1. How to develop commercially valuable new ideas. Food or flower production in greenhouses by hydroponics is a high-investment business, the costs, according to one authority, running to \$25,000 a year per acre. (1945) The advice given by one grower is that the 10% to 25% advantage in economy and yield which hydroponics gives is beset by the danger of damaging or destroying your plants through some mistake, due to carelessness or inexperience.

While hydroponics gives better control, it also requires more extensive and precise knowledge. Without a knowledge of chemistry, a person could probably be successful in greenhouse production in soil; in soilless gardening, he would be very handicapped. On the other hand, to some people, manipulating solution acidity and chemical concentrations is more interesting than filling pots with mixtures of leaf mold, loam and sand.

The person who is willing to risk capital on the conclusions of his sober best guesses might consider the production of special tropical fruits as one possibility. Gericke showed that papayas could be raised by hydroponics in greenhouses. There are many delectable tropi-

cal fruits, some of which might do well in hydroponic greenhouses.

2. How to do scientific work in soilless plant culture. Growing plants in controlled solutions for scientific purposes is over two hundred years old, while practical hydroponics is just over twenty years old. Complete control of all possible factors in plant experiments has been a developing ideal through the years. The California Institute of Technology has just erected a new plant physiology research laboratory in which aseptic conditions are to prevail. Insects are excluded by electric screens. Natural and artificial light and temperature conditions are controlled. Solution and soil methods of growth are to be tested, and data on factors of growth and yield of crops are being sought.

Those desiring to work professionally in this fascinating field will, of course, prepare themselves thoroughly, by careful study of many phases of science, including biology, botany, chemistry, genetics, and possibly physics and mathematics, always working toward their goal of specializing in plant physiology. In scientific work, solution culture of plants has always been regarded as a technique or tool of plant physiology, rather than a separate field of scientific work.

* * *

ASSIGNMENTS

Some suggested projects in soilless gardening pioneering

1. CHEMICULTURE CLUB: An activity for your group: Carry out a group project to plan and organize the most practical and efficient home production unit for a family of four or five.

2. COMMERCIAL POSSIBILITIES: Some ideas to develop for profit.

- a. Survey the market possibilities and the production methods for some specialty such as certain tropical fruits.
- b. Analyze the costs and problems involved in producing and selling or renting bucket-and-box units of 10 to 15 sq. ft. area, with a booklet of instructions, and a prepared complete mixture of chemicals in 5 lb. packages for use by amateurs at home. If the prospects are favorable, undertake this project.
- c. Investigate the costs and problems involved in supplementing wood ashes with nitric and sulfuric acids to make a complete balanced mixture for soilless gardening. (Get a chemical analysis of the ashes, and plan the supplementing elements needed.) Undertake to package and sell the mixture, if your analysis proves it is a practical idea.

3. VOCATIONAL SCIENTIFIC RESEARCH: Survey the opportunities: In

cooperation with a vocational counselor, take tests of your aptitudes for scientific work of this kind. Study information on the length and kind of training, the types of work done, the salary and conditions of work, of a plant physiology and nutrition scientist.

4. SAMPLE PROBLEM FOR RESEARCH: Development of a new device for solu-

tion control: The total amount of solutes in the solution is of considerable importance in soilless culture, as it affects the ease or difficulty of intake of water by the roots. This is referred to as "osmotic pressure" of the solution, and may unscientifically be described as the "drawing power" of the solution, or resistance to being "sucked in" by the roots. This is proportional to the

total moles per liter of dissolved particles, or molecules of solutes in the solution. While these are somewhat difficult to measure, an indirect measure that is roughly proportional to it is the conductivity of the solution, and this is much easier to measure, by means of a wheatstone bridge circuit. A useful project, therefore, would be to obtain or make a conductivity meter and use it to maintain a closely controlled osmotic pressure of solution. The construction and use of a conductivity meter is described in text-books of electr-chemistry. Moreover, it may even be possible by its use to eliminate some of the chemical testing that is otherwise necessary. Automatic devices using the conductivity meter are used in industry to maintain constant pH. This might also be a valuable innovation in control of solutions. Conceivably, such developments might reduce the control operations in large installations to a new minimum.

EVALUATION

Some suggested means of checking your progress

1. IMPROVEMENT OF YOUR GROUP PROJECT: The test of experience: Try out the suggested solutions of problems in actual practice before accepting them as tested solutions. (This is like kitchen-testing of recipes before including them in a cook book.)
2. GROUP EVALUATION: Use the slip technique: Near the end of a course in soilless gardening, or toward the end of a chemiculture club project, collect on slips suggestions for improved organization and planning of group research projects, directed to different

stages of the project, (such as choice, procedures for formulating problems, obtaining suggested solutions, testing solutions offered, recording and presenting results of the work.)

3. INDIVIDUAL EVALUATION: Some suggested methods:

a. Objective tests: Answer and be checked on questions like:

- (1) () (X) More research needs to be done on the practicality of growing wheat by hydroponics.
- (2) (X) () High-mineral products can be raised more economically in soil than in hydroponics.
- (3) (X) () Foods of a high water, starch, or sugar content can be raised economically in hydroponics.
- (4) (X) () The cost of chemicals alone in wheat production by soilless gardening would be more than the price of the wheat.

b. Advice: Ask for help from those who should know: Have your exploratory study of plant physiology as a vocation checked by a vocational counselor.

SOURCES

Materials to help in your search for sound new ideas

- 1. BOOKS: Reserve Shelf Citations:** Bear, 190-4, 199-230; Ellis, 227-236.
- 2. MAGAZINES: Articles describing experimental procedures:** Magazine references Nos. 3, 13, 19, 20, 21, 34, and 39.
- 3. ENCYCLOPEDIA ARTICLES: Short comprehensive treatments of scientific principles and laws:** See articles on plants, plant physiology,

plant nutrition, hydroponics, osmosis, photosynthesis, solutions, and other chemical, physical, and bio-chemical, etc., subjects.

4. TEXTBOOKS: More adequate and thorough treatments of scientific principles, laws, and discoveries: Consult and study textbooks, and possibly take courses in chemistry, physics, horticulture, etc., as you find you have need of them.

LIST OF 16 MM. MOTION PICTURE FILMS

Titles and descriptions as given in: The H. W. Wilson Co.: Educational Film Guide. The H. W. Wilson Company, 1948, qu.v. for abbreviations and publisher information. These films are available from the University of California Dept. of Visual Instruction, Extension Division, 813 S. Hill St., L. A. 14, Calif.

- a. HUNGER SIGNS. 15min sd color loan 581

Nat Fertilizer. sh-c-adult

The nutrition of plants and animals is the sustaining story of the picture. The picture opens with illustrations of virgin soil and rapidly reviews the soil history. The raw materials required to produce 100 bushels of corn are illustrated graphically, followed by pictures of plants and animals suffering from malnutrition. The fundamental causes and methods to correct nutritional deficiencies are presented.

- b. PLANT SPEAKS THRU DEFICIENCY SYMPTOMS. 25min sd color loan 581

1945 Am Potash Institute. jh-sh-c-adult

Pictures soil depletion, erosion, and deficiency symptoms on plants.

- c. PLANT SPEAKS THRU LEAF ANALYSIS. 18min sd color loan 1945 581

Am Potash Institute. jh-sh-c-adult

Evaluates leaves in plant growth and leaf analysis in determining fertilizer needs.

- d. PLANT SPEAKS THRU TISSUE TESTS. 14min sd color loan 1945 581

Am Potash Institute. jh-sh-c-adult

Shows the value of tissue testing and the procedure for testing plant tissues in the field.

- e. STUDY OF MINERAL ELEMENT DEFICIENCIES IN PLANT GROWTH. 31min 58l
sl, sd \$75-\$175; rent \$6-\$7.50 1937 Rutgers c-adult

Shows and describes first the natural growth movements of plants as revealed in stop-motion photography, and the photographic device developed at Rutgers University for the taking of stop motion pictures.

Stop motion pictures of seven tobacco plants through the entire cycle of growth show that if any one of the six necessary elements in plant growth is entirely withheld, the plant is retarded or killed.

The film shows and describes experiments on cotton, tobacco, peas, buckwheat and tomato plants grown under controlled laboratory conditions. The results of experiments demonstrate the need of the minor elements, boron and manganese, in plant nutrition and establish the fact that these elements are present in sufficient quantity in sodium nitrate as mined and processed.

RESERVE SHELF LIST OF BOOKS

These books are cited throughout the syllabus by the last name of first author.

- a. Bear, firman E., and others: Diagnostic Techniques for Soils and Crops. The American Potash Institute. 1948.
- b. Connors, Charles H. and Tiedjens, Victor A.: Chemical Gardening for the Amateur: Gardening without Soil Made Easy. Wm. H. Wise and Co., New York. Illustrated. 216 pp. of text. 1939.
- c. Ellis, Carlton, and Swaney, Miller W.: Soilless Growth of Plants: Use of Nutrient Solutions, Water, Sand, Cinder, etc. Second Edition. Reinhold Publishing Corporation, New York. 150 pp. 1947.
- d. Gericke, William F.: The Complete Guide to Soilless Gardening. Chemical Publishing Company, Inc., New York. 280 pp. 1940.
- e. Hambidge, Gove: (editor) Hunger Signs in Crops. National Fertilizer Association, 1941.
- f. Laurie, Alexander: Soilless Culture Simplified. McGraw-Hill Book Company, New York. 200 pp. 1940.
- g. Spessard, Earle A.: The Tanks are Coming. Hydroponics, Inc., Little Rock, Arkansas. 155 pp. 1948.
- h. Turner, Wayne I., and Henry, Victor M.: Growing Plants in Nutrient Solutions, or Scientifically Controlled Growth. John Wiley and Sons, New York. 125 pp. of text. 1939.

BIBLIOGRAPHY: ADDITIONAL BOOKS AND PAMPHLETS

- Dawson, C. D., and Dorn, M. V.: Plant Chemiculture, a Guide to Experiments in Growing Plants without Soil. The Authors, Los Angeles, Calif. 3d revised edition. Illustrated, about 130 pp. 1939.
- Fawcett, G. S. and Stroughton, R. H.: The Chemical Testing of Plant Nutrient Solutions. The Tintometer Ltd. The Colour Laboratory. Salisbury, England. 1944.
- Hoagland, D. R., and Arnon, D. I.: The Water-Culture Method of Growing Plants without Soil. California Agricultural Experiment Station Circular 374. 1938.
- Matlin, D. R.: Growing Plants without Soil: The A-B-C of Plant Chemiculture. 2nd revised edition. Chemical Publishing Company, Inc., New York. Illustrated, about 50 pp. 1940.
- Phillips, A. H.: Gardening without Soil. Chemical Publishing Company, Inc., New York. Illustrated, about 140 pp. 1940.
- War Department Technical Manual: Nutriculture. No. 20-500. 1946.
- Withrow, R. B., and Biebel, J. P.: Nutrient Solution Method of Greenhouse Crop Production. Purdue University Agricultural Experiment Station Circular 232, 1938.

BIBLIOGRAPHY: MAGAZINE ARTICLES

1. Moliter, C.: "Magic in the Garden." Colliers, 121:40, (April 17, 1948). (Enthusiastic; somewhat superficial; slightly inaccurate.)
2. "Food from Soilless Gardens." Science News Letter, 52:125, (August, 1947).
3. Stuart, N. W.: "Growing Plants without Soil." Scientific Monthly, 66:273-82, (April, 1948). Illustrated, tables. (The most complete recent general article on soilless gardening. Conservative. Good bibliography.)
4. Thone, F.: "Hydroponics Harvest Reaped." Science News Letter, 52:154-6, (September 6, 1947). Illustrated, (Good description of the army's experience with hydroponics, especially in Japan. Includes cost data.)
5. Holman, R. L.: "Farming without Soil." American Mercury, 62:96-100, (Jan. 1946). (New developments in hydroponics.)
6. "Flowers Bloom Year Round with Chemicals, Lighting." Science News Letter, 50:344, (Nov. 30, 1946). (Combining hydroponics with special lighting to influence blooming period of flowers.)
7. Moore, W. R.: "Greens Grow for G. I.'s on Soilless Ascension." National Geographic Magazine, 88:219-30, (Aug. 1945). Illustrated. General information about soilless gardening as done on Ascension.)
8. "Substitute for the Good Earth." Business Week, p. 48 (April 27, 1946). (Limitations and best business applications of chemical gardening.)
9. Davids, R. C.: "Uncle Sam, Gardener in Gravel; Army Air Forces'

- Vegetable Growing Program." Better Homes and Gardens, 23:24, (August, 1945). Illustrated.
10. Thone, F.: "Vegetables without Soil; Hydroponics Garden on Ascension Island." Science News Letter, 47:378-9, (June 16, 1945).
 11. "Chemical V-Gardens." Newsweek, 24:86, (Aug. 7, 1944). Illustrated. (Short article tells of convalescent air-force veterans raising vegetables by chemical gardening at Coral Gables, Florida.)
 12. "Convalescent Gardening; A. A. F. Convalescent Centers." Science News Letter, 46:182-3, (Sept. 16, 1944). Illustrated. (Same topic as previous article.)
 13. "Cotton Hydroponics May Point Way to Better Material for Tires." Scientific American, 170:78, (Feb. 1944). (Describes research methods to discover relation of plant nutrition to length of cotton fibers.)
 14. "Soilless Farms on Islands; Fresh Vegetables for U. S. Army Air Force Personnel." Science News Letter, 46:36, (July 15, 1944).
 15. "Vegetables for Greece; Soilless Gardens Springing up all over the World." Science News Letter, 47:21, (Jan. 13, 1945).
 16. "Plant Magic." Popular Mechanics, 81:34-7, (Jan. 1944). Unusual facts about plant development and special chemicals.)
 17. Holman, R. L.: "Farming without Dirt." Canadian Forum, 22:152-3, (Aug. 1942). (Informative general article outlining progress of soilless gardening.)
 18. "Soilless Gardening! Apartment Roof! N. Y. City." American Home, 28:22-3, (June, 1942).
 19. "Soilless Gardening; Water Vapor Method." Science, 95: Sup 8

(May 15, 1942). (A description of a new technique, namely, spraying solution on the roots in a fine mist.)

Same article also in Science News Letter, 41:310-11, (May 16, 1942). Illustrated.

20. Thone, F.: "Chemical Controls." Science News Letter, 42:141, (Aug. 29, 1942). (Hormone and other chemical growth regulators.)
21. "Grow Bigger Crops with Hormone Treatment." Science News Letter, 41:37, (Jan. 17, 1942).
22. Gericke, W. F.: "Challenge of Soilless Gardening." Science Digest, 8:8-14, (July, 1940). (A good condensed description of hydroponics, taken from Gericke's book; gives important principles of soilless gardening.)
23. Johnson, W.: "Gardening without Soil." Arts and Decoration, 53:46, (Jan. 1941). Illustrated.
24. Brown, G.: "Growth without Soil; Sand Culture and Subirrigation Systems, with Formula." Good Housekeeping, 109:42-3, (Oct. 1939). (A woman amateur grows vegetables and flowers in a city apartment.)
25. "Hydro-Sand Culture." Nature Magazine, 33:189, (April, 1940).
26. Thone, F.: "Multiple Cropping." Science News Letter, 37:190, (March 23, 1940). (Efficiency Increased by Multiple Cropping.)
27. Taylor, F. J.: "Nice Clean Gardening." Readers Digest, 35:106-8, (Aug. 1939). From Rotarian. Enthusiastic, informative article.)
28. "No Short-Cut Horticulture." Scientific American, 163:140-2, (Sept. 1940). (Limitations and cautions. Plant hormone action.)
29. Gettins, E. G.: "Now Anyone Can Try Tank Farming on a Small Scale." Popular Science, 136:180-1, (March, 1940). Illustrated,

diagrams. (Instructions for home-type projects.)

30. Huttenlocher, F.: "Now I'm a Soilless Gardener." Better Homes and Gardens, 19:34, (Oct. 1940). Illustrated.
31. "100 Tons to the Acres. W. F. Gericke, Soilless Crop Expert." Newsweek, 14:34, (Aug. 21, 1939). (Very optimistic yield and cost figures on growing crops by multiple-crop method.)
32. McLeod, F. T.: "Report on Chemiculture." House and Garden, 77:52, (June, 1940). Illustrated.
33. "Roots without Soil." House Beautiful, 82:82-3, (Apr. 13, 1940). Illustrated.
34. Thone, F.: "Science Stunts for the Gardener." Science News Letter, 37:234-6, (April 13, 1940). (On the use of hormones, etc.)
35. Shive, J. W.: "Sketch of the Development of Soilless Gardening." Scientific Monthly, 51:233-40, (Sept. 1940). Bibliography. (Describes the development of soilless gardening. Conservative.)
36. Livingston, B.E.: "Solution Gardening." Scientific Monthly, 51:15-21, (July 1940). Bibliography. (Excellent favorable article, scholarly but not technical.)
37. Hoagland, D. R., and Arnon, D. I.: "Water Culture Method of Growing Plants." Smithsonian Report, 1938:461-87.
38. "Success of Pan-American Airways Chemical Gardens on Pacific Island." Business Week, p. 38. (July 27, 1940). (Good popular survey article, conservative in tone.)
39. Hawley, G. G.: "Whither Soilless Growth?" Nature Magazine, 33:306-7, (May, 1940). (Short, descriptive, favorable article.)
40. Wing, A.: "You Don't Need Soil to Grow Plants." Woman's Home

Companion, 68:80, (Jan. 1941).

41. Olcott, H. S.: "Sand Culture of Cotton Plants." Science News Service, 89:608, (June 30, 1939). (Description of experiments.)
42. Auchter, E. C.: "Interrelation of Soils and Plant, Animal and Human Nutrition." Science News Service, 89:421-7, (May 12, 1939).
Bibliography. (Describes probable effect of mineral deficiencies of soils on plant, animal, and human nutrition. Advocates research and planning to produce better food.)

SOURCES USEFUL FOR ORIENTATION

Materials to help you get a quick view of soilless gardening

1. FILMS: Film Nos. 1, 2, and 5 in the list at the back of this syllabus should be helpful.
2. PICTURES IN RESERVE SHELF BOOKS: (See the Reserve Shelf List for the full titles of the books):
 Connors, Frontispiece, pp. 16, 22, 39, 44, 47, 49, 64, 82, 92, 99, 104, 107, 112, 145, 161, 179, 192, 208; Ellis, Frontispiece, 2, 5, 7, 9, 24, 25, 26, 29, opp. 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 72, 91, 97, 98, 99, 152, 153, 200, 203, 204, 297; Gericke, Dust jacket, 25, 28, 31, 125, 127, 129, 131, 133, 140, 148, 151, 152, 165, 168, 170, 186, 187, 191, 194, 213, 215, 218, 223, 225, 264; Turner, Frontispiece, 2, 5, 10, 11, 34, 37, 38, 58, 108, 118.
3. READINGS IN RESERVE SHELF BOOKS: Connors, v-vi, 23-34, 217-21: Ellis, 19-22; Gericke, 1-6, 257-270; Spessard, vi-viii, 1-14, 141-55; Turner, ix.
4. MAGAZINE ARTICLES: Most of those cited in the appendix, "Bibliography: Magazine Articles", will be helpful, but especially nos. 3, 4, 8, 22, and 24.